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# MASTER BOOK

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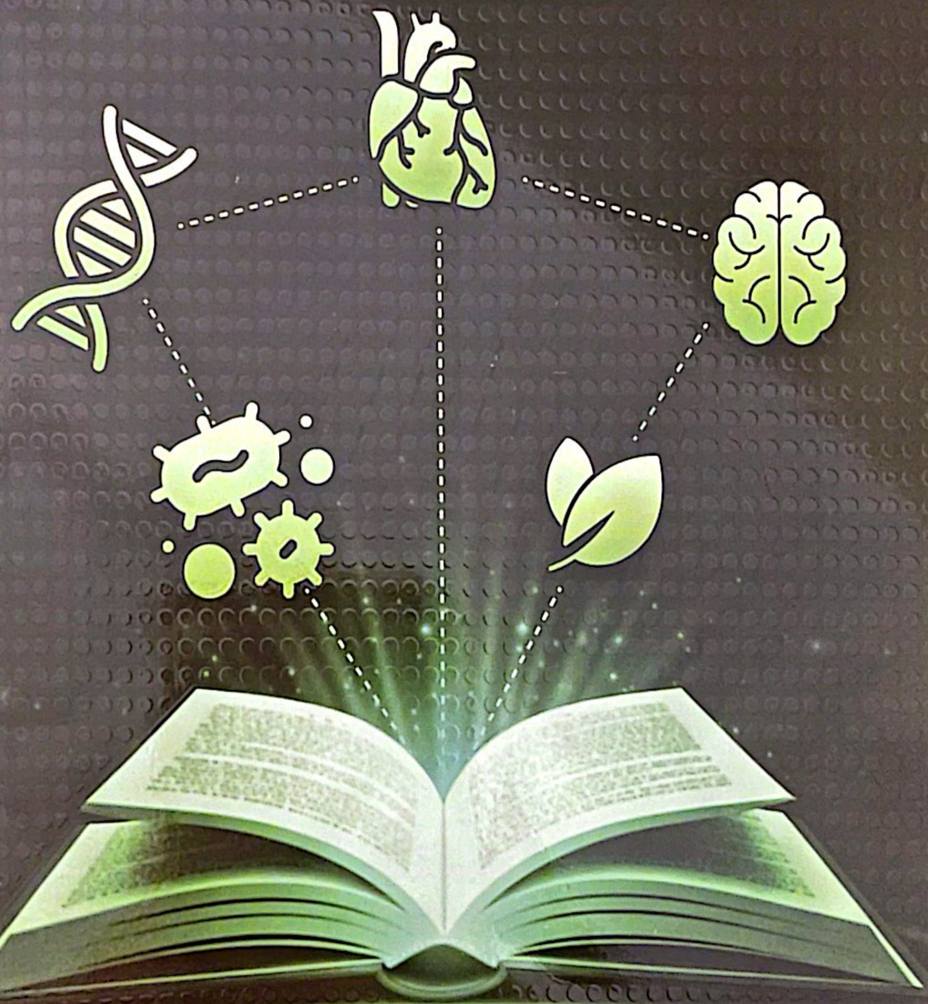

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***HOW TO CRACK MDCAT** with*
***FULL MARKS** IN BIOLOGY*

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# MASTER BOOK BIOLOGY

*How to CRACK MDCAT with Full MARKS in BIOLOGY*



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## MENTR (FORMERLY INSIGHT MDCAT)

A platform designed to help you achieve your dream of getting into medical college by providing insights from those who have successfully cracked the **MDCAT.**

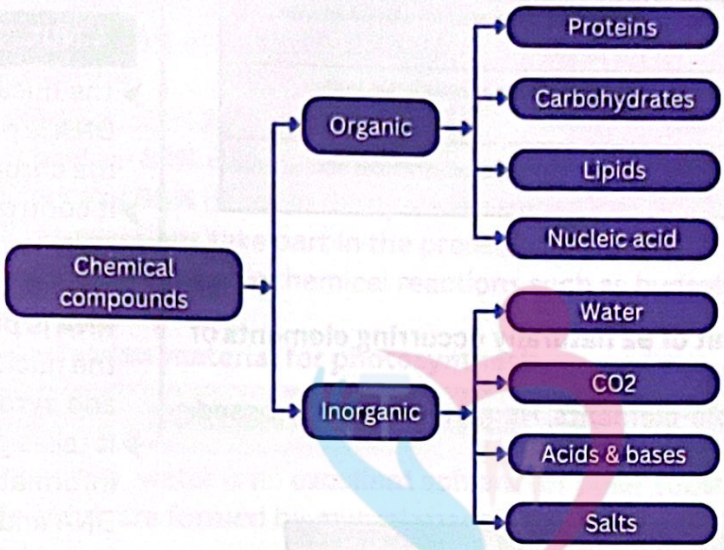
At Mentr, we sat down at **King Edward Medical University, Lahore**, and developed this Master Book for you. More than anything else, we are committed to solving the problems that every MDCAT aspirant faces. To support you further, we have created **THE MDCAT WORLD**—a session that includes everything you could dream of!

This **MASTER BOOK for Biology** is just the tip of the iceberg—there's much more waiting for you! Join us and get on the path to success!

# BIOLOGICAL MOLECULES

## Biological Molecules

- It deals with study of **chemical components** and **chemical processes (metabolism)** occurring in living organisms.
- All living things are made of certain chemical compounds which are of two types:




### COMPOSITION

| Chemical components | Bacteria cell (prokaryote) | Mammalian cell (human |
|---|---|---|
| Water | 70% | 70% |
| Proteins | 15% | 18% |
| Carbohydrates | 3% | 4% |
| Lipids | 2% | 3% |
| DNA | 1% | 0.25% |
| RNA | 6% | 1.1% |
| Other organic molecules (enzymes, hormones, metabolites) | 2% | 2% |
| Inorganic (Na+, K+ etc) | 1% | 1% |



### PTB

- Life of an organism depends upon the ceaseless chemical activities in its cells.
- This chemical activity is maintained with a high degree of organization.
- All the chemical reactions taking place in call are called metabolism.
- Metabolism is characterized as:

### BTB

- **Protoplasm** is the living content of the cell that is surrounded by a plasma membrane.
- It is a general term for cytoplasm and nucleoplasm.
- Trace elements are also called **dietary elements.**

### KPK

- Water is the most abundant of all the compounds in protoplasm and forms three fourth of the body.
- **Proteins** are the **most abundant organic compounds** in body.
- Proteins have structural and functional roles in cell.

### FUNDAMENTAL BIOMOECULES

#### 1. CARBOHYDRATES

- They are present in the cytoplasm of the cells and provide fuel for the metabolic activities of the cell.

#### 2. PROTEINS

- They are present in the membranes, ribosomes, cytoskeleton and enzymes of the cell.

| Anabolism | Catabolism |
|---|---|
| Need energy | Energy is released |
| Simpler compounds join | Larger molecules break |
| Complex compounds are formed | Smaller simpler molecules formed |
| Such as photosynthesis | Such as respiration |

- Interconversions of carbohydrates, proteins, and lipids that occur continuously in living cells are examples of co-ordinated catabolic and anabolic activities.

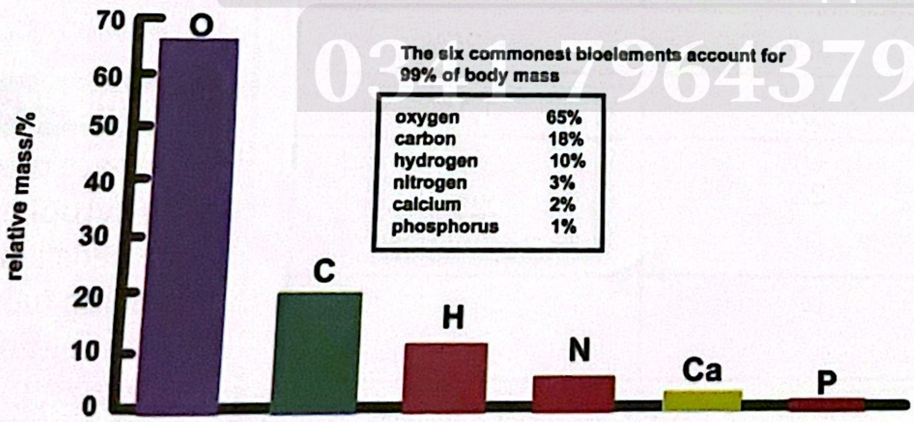
| | |
|---|---|
| 1. C–N bond | Hydrocarbon (potential source of chemical energy for cellular activities) |
| 2. C–N bond | Peptide bond (forms proteins which are very important due to their diversity in structure and function) |
| 3. C–O bond | Glycosidic bond (provides stability to complex carbohydrates molecules) |

## FTB

- Approximately **25 elements out of 92 naturally occurring elements** of earth are found in living beings.
- These are called **biogenic or bio-elements.** Human body is composed of only **16** of these bioelements.
- These are classified as:

| Major | Minor | Trace |
|---|---|---|
| 6 elements (99% of body) | 1% of body | 0.01% of body |
| Oxygen 65% | Potassium 0.35% | Iron |
| Carbon 18% | Sulphur 0.25% | Copper |
| Hydrogen 10% | Chlorine 0.15% | Manganese |
| Nitrogen 3% | Sodium 0.15% | Zinc |
| Calcium 2% | Magnesium 0.05% | Iodine |
| Phosphorous 1% | - | etc |






**Other bioelements include (about 1% - potassium (0.35%), sulphur (0.25%), chlorine (0.15%), sodium (0.15%), magnesium (0.05%), iron (0.004%), copper (trace), manganese (trace), zinc(trace), iodine (trace)**

- **Condensation** is the formation of dimer (polymer) when water molecule is released.
- It is called **dehydration synthesis** because water is removed, and a new bond is formed.

## 3.LIPIDS

- They are present i[n] the membranes a[nd] cytoplasm of the cell.
- Lipids provide a reserved energy source, shape, protect and insula[te] the cells.

## 4.NUCLEIC ACIDS

- The nucleic acid **DNA** is present in the chromosome.
- It controls the cell activity.
- The nucleic acid **RNA** is present in the nucleoplasm and cytoplasm.
- It takes genetic information from DNA and play role in protein synthes[is]

## SCIENCE TIDBITS

- Don't confuse involvement of water in hydrolys[is] with making a solution, in which the role of water to act as a solve[nt] rather than takin[g] part in chemical reaction.
- Also do not assu[me] that this breakd[own] releases energy, which is usually produced when [the] simpler substan[ces] are oxidized in respiration.
- Hydration is yet another comple[tely] different proces[s] involving the addition of wate[r] but not breakin[g]

- Condensation does not take place unless the proper enzyme is present, and the monomers are in an activated energy- rich form.
- **Hydrolysis** is the **reverse process of condensation** in which polymers are broken into monomers by the addition of water.
- Actually, all **digestion reactions** are **examples of hydrolysis**, which are controlled by enzymes such as carbohydrases, proteases, lipases, nucleases.

## IMPORTANCE OF WATER

- Water is the most abundant compound in all organisms.
- It varies from **65-89%** of the body (two third of the earth)
- Human tissues like:
- **Bone** and **seed** contain **20%** water.
- **Brain** cells contain **85%** water.
- **Jelly fish** contains **99%** of water (body shows transparency).
- Almost all the reactions take part in the presence of water.
- It also takes part in many biochemical reactions such as hydrolysis of macromolecules.
- It is also used as **raw material for photosynthesis.**

### SOLVENT PROPERTIES

- Due to its polarity, water is an **excellent solvent** for polar substances.
- The bonds which are formed by mutual sharing are called **covalent compounds.**
- Covalent compounds may be polar or non-polar.
- **Polar compounds** like ionic compounds are easily dissolved in water due to positive and negative ions.
- **Non-polar or non-ionic substances** having charged groups in their molecules are dispersed in water.
- When in solution, ions and molecules move randomly and are in a more favourable state to react with other molecules and ions.
- It is because of this property of water that almost **all reactions** in cells occur in **aqueous media.**
- In cells all chemical reactions are catalyzed by enzymes which work in aqueous environment
- Non-polar substances such as fat are insoluble in water and help to maintain membranes which make compartments in cell.

### HEAT CAPACITY

- Water has great ability of absorbing heat with minimum of change in its own temperature.
- Specific heat of water is the **number of calories required to raise the temperature of 1g of water** from **15** to **16°C** is **1.0 (4.18 joule)**.
- This is because much of energy is required to break **H-bonds**.
- Water thus acts temperature stabilizer for organisms.
- Hence protects living material against sudden thermal changes.

### HEAT OF VAPORIZATION

- Water absorbs much heat as it changes from liquid to gas.
- Heat of vaporization is expressed as **calories absorbed per gram vaporized.**

bonds

**BTB**

**Blood contains 88% of water.**

**KPK**

- Water is essential for existence of protoplasm because protoplasm can't survive if its water content is reduced as low as **10%**.
- Hydrogen bonds are weaker than covalent bonds but still cause water molecules to remain attached together.
- Water dissolves all minerals present in soil which are absorbed by plant roots and transported to other tissues.
- The presence of water molecules cause water to remain in liquid rather than change to ice or steam.
- Water would boil at **-80°C** and freeze at **-100°C** if hydrogen bonding is removed.
- In such conditions life for living organisms would become impossible.
- The Ice layer at surface acts as an insulator to prevent the water below it from freezing thus

- It is the amount of heat required to convert one gram of liquid water into vapours at its boiling point.
- Specific Heat of vaporization of water is **574kcal/kg.**
- It plays role in regulation of heat produced by oxidation.
- It also provides **cooling effects** to plants when water is transpired and animals when water is perspired and thus helps animals and plants to get **rid of excess body heat.**
- Evaporation of only two ml out of one litre of water lowers the temperature of the remaining **998ml by 1°C.**

## COHESION AND ADHESION

- **Cohesion** is the **attraction among the water molecules** enabling the water molecules to stick together & due to it water flows freely.
- Water molecules also have **attraction to polar surfaces** called as **adhesion.**
- Both cohesion and adhesion are **due to hydrogen bonds** among water molecules.
- These properties of water enable it to circulate in living bodies and to act as transport medium.

## IONIZATION OF WATER

- The water molecule ionizes to form **$H^+$** and **$OH^-$** ions.
- This reaction is reversible, but an equilibrium is maintained.
- It produces equal number of both ions at **25°C** as **$10^{-7}$mol/litre.**
- The **$H^+$** and **$OH^-$** ions affect and take part in many of the reactions that occur in cells.
- The ions produced help maintaining the **pH** for proper functioning.
- The presence of ions is important for the normal functioning of enzymes.

## PROTECTION

- Water is effective lubricant that provides protection against damage resulting from friction.
- Tears protect the surface of eye from rubbing of eyelids.
- Water also forms a fluid cushion around organs that helps to protect them from trauma.
- e.g. Cerebrospinalfluid (**CSF**) around central nervous system and amniotic fluid around foetus prevent from trauma).

**FTB**

## HYDROGEN BONDING

- The polarity of water molecules makes them interact with each other.
- The charged regions on each molecule are attracted to oppositely charged regions on neighbouring molecules, forming weak bonds.
- Since the positively charged region in this special type of bond is always an H atom, the bond is called a hydrogen bond.
- This bond is often represented by a dotted line because a hydrogen bond is easily broken.
- Because of hydrogen bonding, water is a liquid at temperatures

- protecting the acquatic organis[ms] from freezing.
- Water can fill tub[es] vessel and still flows so that dissolved molecules are evenly distributed throughout the system.

### WATER EXPANDS A[T] LOW TEMPERATU[RE]

- Water has a unique property, as it expands (density ↓↓) when temperature falls below **4 °C**.
- Water is **most he[avy] at 4 °C**.
- Water body freez[es] on the surface at low temperature

suitable for life.

## HYDROPHOBIC EXCLUSION

- Reduction of contact area between water and hydrophobic substance which are placed in water.
- If you place few drops of oil on surface of water water, oil drops tend to coalesce into a single drop.
- Hydrophobic exclusion plays key roles in maintaining the **integrity of lipids bilayer membranes.**

## LOWER DENSITY OF ICE

- Ice (solid water) floats on water because ice is less dense than water.
- Ice has a giant structure and show maximum number of hydrogen bonding among water molecules; hence, they are arranged like a lattice.
- In freezing weather, ice forms on the surface of ponds and lakes forming an insulating layer above the water below.
- This provides a living environment for some organisms until the ice melts.
- Organisms can also live under the ice.

# CARBOHYDRATES

- Carbohydrates means **hydrated carbons.**
- They constitute carbon, hydrogen and oxygen.
- Hydrogen and oxygen are found in the same ratio as water **2:1**.
- Chemically, carbohydrates are denied as **polyhydroxy aldehydes or kentones**, or complex substances which on hydrolysis yield polyhydroxy aldehyde or ketone subunits.
- Their general formula is $C_x(H_2O)y$ .where x is whole number from **3 to many thousands.**
- Where y may be the same or different whole number.
- Carbohydrates are also called **'saccharides'** (derived from Greek word **'sakcharon'** meaning sugar) and are classified into **three groups.**



**FTB**

| Monosaccharides | Oligosaccharides | Polysaccharides |
|---|---|---|
| They consist of single saccharide unit. | They are composed of 2 to 10 saccharide units. | They are composed of more than 10 saccharide units. |
| They are simplest carbohydrates; therefore, they can not be further hydrolyzed. | They have less complex structure, so upon hydrolysis they yield at least 2 and maximum 10 monosaccharides. | They have highly complex structure, so upon hydrolysis they yield at least 11 monosaccharides. |
| They are highly soluble in water. | They are less soluble in water. | They are generally insoluble in water. |
| They are sweetest among all carbohydrates. | They are less sweet in taste. | They are tasteless. |

**PTB**

- Carbohydrates occur most abundantly in cells.
- They are found in all organisms and all parts of body.
- They play **both structural** and **functional roles.**

**BTB**

The chemistry of carbohydrate is determined by aldehyde and ketone group e.g. aldehyde is very easily oxidized and hence are **powerful reducing agents.**

**KPK**

- Carbohydrates are most abundant organic biomolecules in nature.
- They perform the following functions

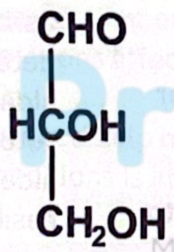
**SOURCE OF ENERGY**

- The **C-H bonds** in the carbohydrate molecules are broken down during **respiration** and the stored energy in these bonds is released which is

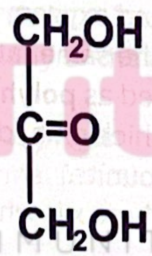
- Simple Carbohydrates are the main source of energy in cells.
- Some carbohydrates are the main constituents of cell walls in plants and micro-organisms.
- The **sources** of carbohydrates are **green plants,** and they are the primary products of photosynthesis.
- Carbohydrates in cells combine with lipids and proteins to form **glycoproteins** and **glycolipids.**
- Both have structural role in extracellular matrix of animals and bacterial cell wall.
- Both these conjugated molecules are components of biological membranes.

## MONOSACCHARIDES

- Monosaccharide are the **true carbohydrates.**
- They are simplest form of sugar and are **sweet** in taste.
- They **can't be hydrolysed** into simpler units.
- They are easily soluble in water.
- In nature monosaccharides with **3 to 7 carbon atoms** are found.
- All the carbon atoms in a monosaccharide except one has hydroxyl group.
- The remaining carbon is either a part of ketone or aldehyde group.
- The sugar with aldehyde group is called **aldo sugar** and that with keto group is called **keto sugar.**

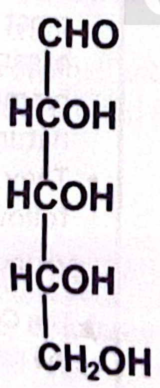


**Aldehyde form**

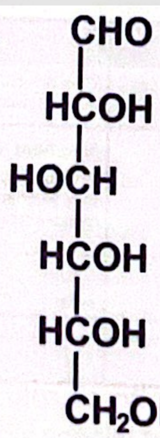


**Keto form**

- Specific formula for monosaccharide is: **$C_n(H_2O)n$,** where n is number of carbon atoms.



**Ribose (pentose sugar)**



**Glucose (A Hexose sugar)**

- On the basis of number of number of carbon atoms, monosaccharides are classified into **five groups:**

made available to the cells for performing various functions.

- Human blood contains **100 mg** of glucose per **100 ml** of blood.

**STORAGE MOLECULES**

- They are stored in cells as reserve food.
- **Grapes** contain as much as **27% glucose.**
- Honey contains large amounts of glucose and fructose.
- Some of these polysaccharides such as starch and glycogen excess amount of food is stored for future use.

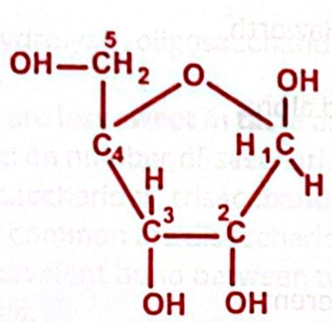
**STRUCTURAL MATERIALS**

- **Cellulose** is the major structural component of cell walls of green plants.
- **Chitin** is the structural component of exoskeleton of arthropods.

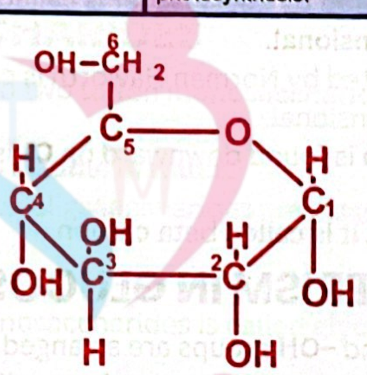
**KPK**

- Monosaccharides are the **white crystalline**
- **powders.** Optical isomerism is one form of stereoisomerism. Optical isomers are

| Monosaccharides | Formula | Name | Description |
|---|---|---|---|
| Trises (3C) | C3H6O3 | Glyceraldehyde (aldo)<br>Dihydroxyacetone (keto) | Intermediates in photosynthesis and cellular respiration. |
| Tetroses (4C) | C4H8O4 | Erythrose (aldo)<br>Erythrulose (keto) | Rare in nature and occur in some bacteria intermediate in bacterial photosynthesis |
| Pentoses (5C) | C5H10O5 | Ribose (aldo)<br>Ribulose (keto) | Ribose and deoxyribose are components of RNA and DNA respectively. Ribulose is an intermediate in photosynthesis. |
| Hexoses (6C) | C6H12O6 | Glucose<br>Galactose (aldo)<br>Fructose (keto) | Glucose is respiratory fuel (initial substrate)<br>Fructose is an intermediate in respiration.<br>Galactose is the component of milk sugar |
| Heptoses (7C) | C7H14O7 | Glucoheptose (aldo)<br>Sedoheptulose (keto) | Intermediate in photosynthesis. |



(a) Ribose
Ribofuranose (D-Ribose)



(b) Glucose
Glucopyranose
(D-Glucose)



- Monosaccharide are usually found in open chain but when dissolved in water most of them are converted into ring chain.
- Two types of rings are found.
- Furanose is a five cornered ring in which **one oxygen atom** and **four carbon atoms** are found.
- Oxygen atom is liked with **C1 and C4.**
- All pentoses and ketohexoses like fructose are converted into furanose ring.
- Pyranose ring is six cornered ring in which one oxygen and **5 carbon** are found and oxygen is linked with **C1 and C5.**
- Only aldohexoses are converted into pyranose rings.

**PTB**

- Pentoses and hexoses are most common.
- Important hexose is glucose which is aldose sugar
- In free form, glucose is present in all fruits abundant in grapes, figs and dates.
- Our blood normally contains **0.08% glucose.**
- In combined form, it is found in disaccharides and polysaccharides.
- Starch, cellulose and glycogen yield glucose upon complete

two compounds which contain the same number and kinds of atoms, and bonds (i.e., the connectivity between atoms is the same), and different spatial arrangements of the atoms, but which have non-superimposable mirror images.

**BTB**

- Ribose is the component of RNA, ATP, NAD, FAD, NADP etc.
- Ribulose is the component of RUBP which is the **$CO_2$** acceptor in photosynthesis.

**BTB**

- The LH sugar have same physical properties as D-glucose, therefore, may be used instead of D-glucose e.g., for baking and also making ice cream.
- The left-handed sugars are not commonly used because they are expensive, not commonly available and their overuse cause serious disturbance for diarrhea patients.
- The laboratory manufactured sugar such as tagatose, sucralose etc. are

hydrolysis.

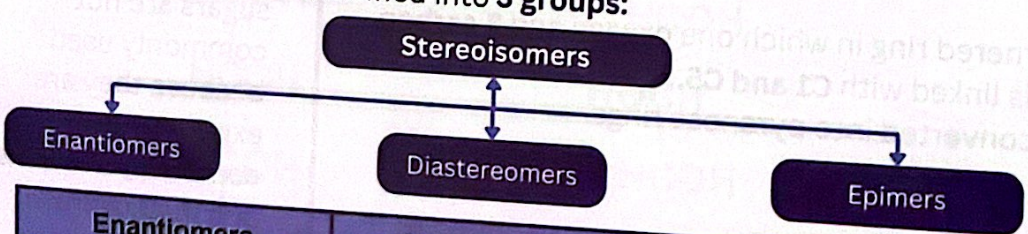
- Glucose is the primary product of photosynthesis.
- For synthesis of **10g of glucose,717.6 kcal of solar energy** is used.
- The energy stored in glucose as chemical energy.
- This energy becomes available to all organisms when it is oxidized in the body.

**FTB**

- Second last carbon is called penultimate carbon e.g., carbon **4 in ribose.**
- In ring structure formation, oxygen atom reacts with penultimate carbon to link.
- Acetic acid, lactic acid and formaldehyde have the same formula as carbohydrates, but they are not carbohydrates.
- While rhamnose (**$C_6H_{12}O_5$**)n does not match the carbohydrate formula but are carbohydrates.
- The ring structure demonstrated by Emil Fischer is called **Fischer projection and it is two dimensional.**
- While the structure represented by Norman Haworth is called Haworth structure and it is three dimensional.
- In ring structure if **–OH group** is found downward on **C1** is called alpha carbon.
- If **–OH group** is upward on **C1** it is called beta carbon.

## STEREOISOMERISM IN GLUCOSE

- Those isomers in which **–H** and **–OH** groups are arranged in different pattern to the asymmetric carbon (chiral carbon) are called stereoisomers.
- An asymmetric carbon (**chiral**) is that which makes four bonds with different atoms.
- Stereoisomers are molecules that have the **same molecular formula and differ only in how atoms are arranged in 3D space.**
- In glucose, **C2, C3, C4, C5** are asymmetric.
- In monosaccharides, the number of stereoisomers depend upon the number of asymmetric carbons and can be calculated by the formula 2n where n is number of asymmetric carbons.
- In glucose, there are **16 stereoisomers.**
- Stereoisomers are classified into **3 groups:**




| Enantiomers | Diastereomers | Epimers |
|---|---|---|
| These are non-superimposable image of each other. | These have different arrangements of H and -OH groups at more than one asymmetrical carbon atoms. These are not mirror images. | These have differed arrangement of H and OH groups at only one asymmetrical carbon are called epimers. |
| D and L isomers of glucose. | d-Glucose and D-altrose. | d-Glucose and d-mannose. |

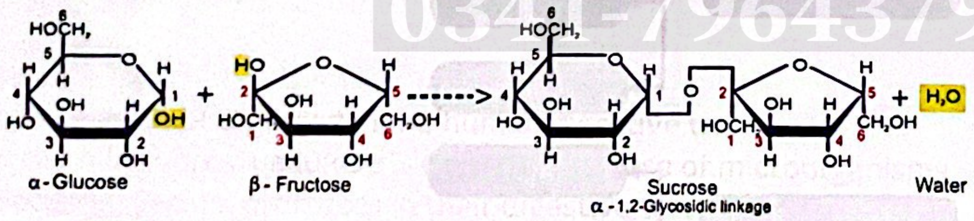
- **D-Isomers** (right-handed form) are those in which asymmetric carbon of penultimate carbon has **–OH group** on right side.
- **L-Isomers** (also called left-handed form) the **–OH group** is on left hand side at penultimate carbon.
- Out of **16 stereoisomers** of glucose, **8 are enantiomers** of the other.

## ARTIFICIAL SWEETNERS

- Laboratory manufactured sugars are left-handed.
- While **naturally occurring sugars** in bodies as **D-sugars.**
- Proteins and cell receptors are designed to react only with D sugars.
- e.g. The enzymes in your stomach can digest only right-handed sugar.
- A suitable analogy is **pair of gloves,** just like the glove fits only one on the proper hand, a right-handed enzyme cannot fit on or react with a left-handed substrate.
- The substrate must fit on the proper active site of the enzyme.
- So, for the left-handed substrate (artificial sweetner) the enzyme must be left-handed.

## OLIGOSACCHARIDES

- On hydrolysis, oligosaccharides yield **two to ten monosaccharides units.**
- They are **less sweet in taste** and **less soluble in water.**
- Based on number of saccharide units, oligosaccharides are classified as disaccharides, trisaccharides etc.
- Most common are disaccharides.
- The covalent bond between two monosaccharides is called **glyosidic linkage.**
- Physiologically important disaccharides are maltose, sucrose, lactose.
- Most familiar disaccharide is sucrose (cane sugar) which on hydrolysis yields **glucose and fructose.**
- The sucrose is formed by the condensation of glucose and fructose. In this reaction, the **-OH** group at **C-1** of glucose reacts with the **-OH** group at **C-2** of fructose, liberating a water molecule forming **a-1,2-glycosidic linkage.**




**BTB**

- **Maltose** is found in our digestive tract as a result of breakdown product during digestion of starch by enzyme called **amylase.**
- It is also used in brewing industries to **synthesize alcohol.**
- In brewing industry, the maltose is produced from the breakdown of barley starch by the help of amylase enzyme.
- This process is known as **malting.**

**FTB**

- The general formula of disaccharides is $C_{12}H_{22}O_{11}$.
- Sucrose is common sweetener used in homes.
- In plants, sucrose is called **transport disaccharide** as prepared food in plants is transported in the form of sucrose.
- It is very soluble and can therefore be moved efficiently in high concentration in plants.
- It is also relatively **unreactive chemically.**
- **Sucrose** and **polysaccharides** are **non-reducing sugars.**
- Glucose and fructose are reducing sugars

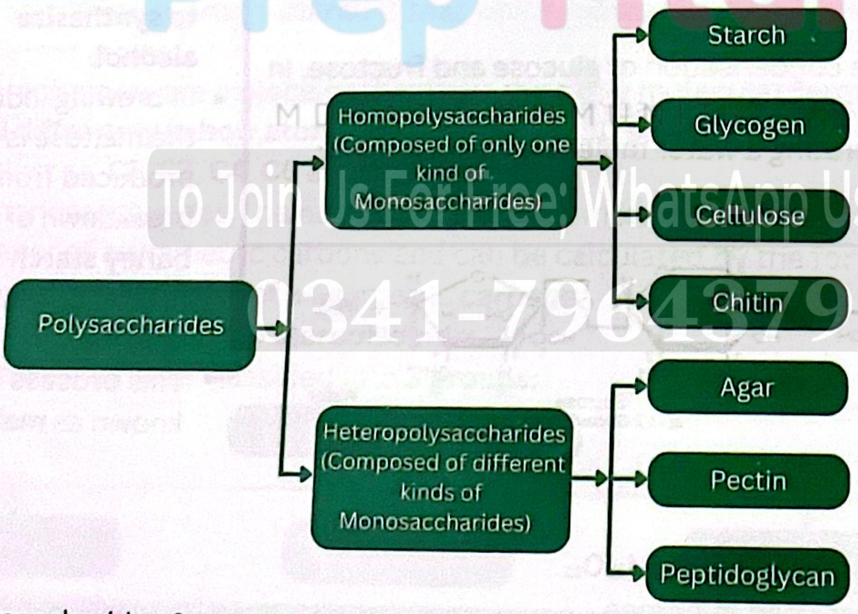
| Sucrose | Maltose | Lactose |
|---|---|---|
| Cane or transport sugar. | Malt sugar. Intermediate disaccharide produced during the breakdown of starch and glycogen. Maltose is found in germinating seeds. | Also called milk sugar and it is an important energy source for young mammals. |
| Upon hydrolysis it yields alpha glucose and beta fructose. | Upon hydrolysis, it yields two alpha glucose molecules. | Upon hydrolysis, it yields beta glucose and beta galactose. |
| **Alpha 1-2 glycosidic linkage** between C1 of glucose and C2 of fructose. | **Alpha 1-4 glycosidic linkage** between C1 of one glucose and C4 of other glucose. | **Beta 1-4 glycosidic linkage** between C1 of galactose and C4 of glucose. |

## POLYSACCHARIDES

- The carbohydrates which **upon hydrolysis yield more than ten monosaccharides** are called **polysaccharides.**
- Polysaccharides are usually branched.
- Polysaccharides are **insoluble or sometimes sparingly soluble in water.**
- These are the largest and most abundant carbohydrate in nature.
- They are **tasteless** and the most complex carbs.
- Some biologically important polysaccharides are starch, glycogen, cellulose, chitin, agar, pectin and dextrin.

**FTB**






- Polysaccharides function chiefly as food and energy stores and structural material.
- They are convenient storage molecule for several reasons.

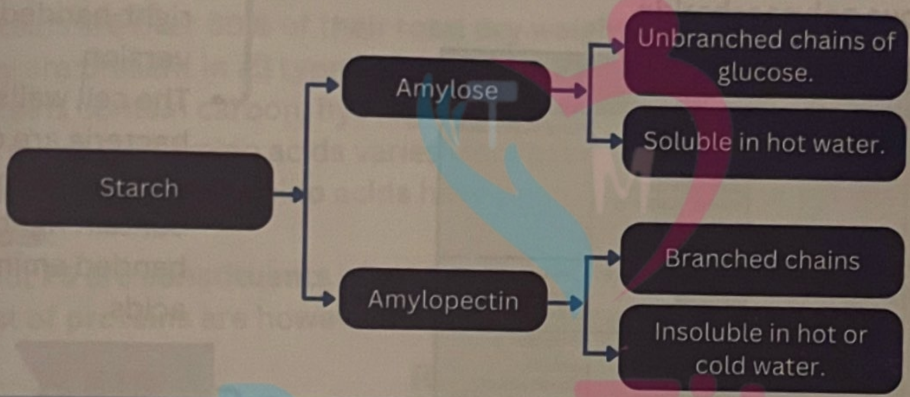
Their large size makes them more or less insoluble in water, so they exert no osmotic or chemical influence in the cell; they fold into compact shapes, and they are easily converted to sugars by hydrolysis when required.

## GLYCOGEN

- It is also called **animal starch.**
- It is the chief form of carbohydrate stored in animal's body.
- It is found **abundantly in liver and muscles,** though found in all animal cells.
- On hydrolysis, it yields glucose.
- It gives **red colour with iodine test.**

## STARCH

- It is found in fruits, grains, seeds and tubers.
- It is **main source of carbohydrates for animals and storage carbohydrate of plants (root, stem, seeds).**
- On hydrolysis, it yields glucose molecules.
- Starches give blue colour with iodine.
- Starches are of **two types:**




## CELLULOSE

- It is the most abundant carbohydrate in nature.
- Cotton and paper is pure form of cellulose.
- It is also the main constitute of cell wall of plants (structural carbohydrate of plants).
- It is **highly insoluble** in water.
- Cellulose gives no colour with iodine test.



### PTB

- Cellulose is not digested in the human digestive tract
- In the herbivores, cellulose is digested because of microorganisms (bacteria, yeasts, protozoa) in their digestive tract.
- These microorganisms secrete an enzyme called cellulase for its digestion.

### FTB

- Starch is digested in oral cavity and in small intestine by the enzyme amylase.
- Amylose has alpha **1-4 glycosidic linkage.**
- Amylopectin has alpha **1-4** and **1-6 glycosidic linkage.**
- Structure of glycogen resembles with amylopectin, but glycogen has more branching.
- Glycogen has also alpha **1-4** and **1-6 linkages.**

### SCIENCE TIDBITS

- Cellulose cannot be digested by human body, but it has to be taken into diet because it works as roughage or fibre, so it prevents abnormal absorption of food in intestine.
- However, herbivore animals have some symbiotic bacteria that secrete **cellulase enzyme** for its digestion.
- Upon hydrolysis it first yields a **disaccharide, the cellubiose** and then cellubiose is further digested into glucoses.
- Glycogen is also found in fungi.

- Structure of glycogen resembles with amylopectin, but glycogen has more branching.
- Glycogen has also alpha **1-4** and **1-6 linkages.**
- Cellulose is formed by condensation of beta glucoses and resembles with amylose starch in such a way that it has unbranched structure.
- It has beta **1-4 glycosidic linkage.**

## CHITIN

- It is the **second most abundant organic molecule** on earth.
- It is major component of cell wall of fungi and exoskeleton of insects and also called fungal cellulose.
- Chitin is the derivative of **N-acetyl glucosamine monomers** which is a modified form of glucose.
- It has **unbranched structure** and has **beta 1-4 glycosidic linkage.**
- Like Cellulose chitin is also not digestible.
- It is a **Structural nitrogenous polysaccharide.**

| Features | Starch | Glycogen (Animal Starch) | Cellulose | Chitin |
|---|---|---|---|---|
| Organism | Plants, Green Algae, Some fungus like protists | Animal, Fungi, Prokaryotes | Plants, Green Algae (Most abundant carbohydrates is murine). Cotton is pure form of cellulose. | Fungi, Arthropods |
| Location | Fruits, grains, seeds, tubers | Most of cells but abundant in liver and muscles. | Main constituent of cell walls | Cell wall of Fungi, Exoskeleton of Arthropods |
| Main Function | Main source of carbohydrates for animals | Chief storage form of carbohydrates in animals. | Main constituent of cell wall of plants. | Protection in animals, Constituent of fungal cell wall |
| Result of Hydrolysis | α-Glucose molecules | α-Glucose molecules | β-Glucose molecules (α-amylase in our gut can not digest it) | N-acetyl glucosamine |
| Solubility | Amylose: Soluble in hot water Amylopectin: Insoluble in hot or cold water. | Insoluble in water. | Highly insoluble in water | Insoluble in water |
| Branching | Amylose: Unbranched Amylopectin: Branched | Branched (More than Amylopectin) | Unbranched | Unbranched |
| Glycosidic Linkage | Amylose: α-1,4 Amylopectin: α-1,4 & α-1,6 | α-1,4 & α-1,6 | β-1,4 | β-1,4 |
| Iodine Test | Blue color with iodine test. | Red color with iodine test. | No colour change on iodine test. | No colour change on iodine test. |

## PROTEINS

- Proteins are the **most abundant organic compound** found in cell.
- Proteins are **polymer of amino acids** or polypeptides.
- An amino acid contains a carbon called **alpha carbon or chiral carbon** also because it is attached with an amino group, carboxylic group, hydrogen and R group.
- R group is variable and varies from amino acid to amino acid.
- R group is H in case of **glycine** and **CH3** in case of **alanine.**
- Amino acids mainly differ due to the type or nature of R group.
- The amino group of one amino acid reacts with carboxylic group of other amino acid releasing a water molecule.
- The linkage group between the hydroxyl group of carboxyl group of one amino acid and the hydrogen of amino group of another amino

### KPK

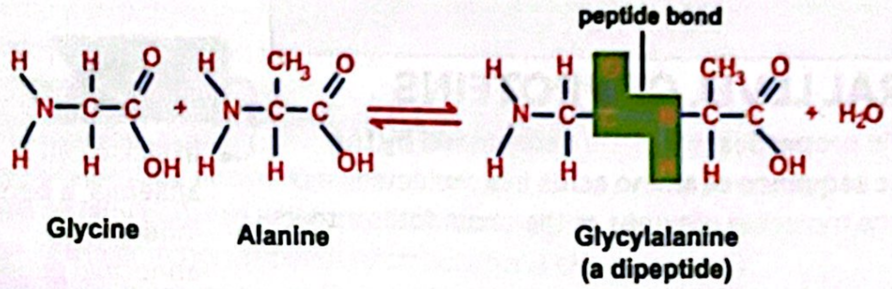
- Amino acids, the building blocks of proteins, are almo all left-handed—o bodies can't manufacture proteins out of th right-handed version.
- The cell walls of bacteria are one exception; they contain right-handed amino acids.

### BTB

- Many amino acids are non-essential because body of the organisms ca prepare them.
- Few amino acids essential becaus body can't prepa them and are required in diet.
- Word protein ha been derived fr **Greek word "proteios" mea prime or first.**

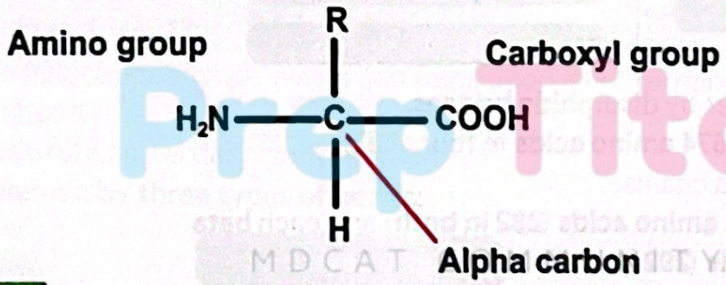
acid release $H_2O$ and C-N link to form a bond called **peptide bond.**

- The product of two amino acids is called **dipeptide** and three is called **tripeptide.**
- A dipeptide has an amino group at one end and carboxylic group at other end so that further peptide bonds are formed to produce tripeptides, tetra-peptide leading to polypeptide chain.




**PTB**

- Proteins are over **50%** of their **total dry weight.**
- They are present in all types of cells and in all parts of the cell.
- Proteins contain carbon, hydrogen, oxygen and nitrogen.
- The number of amino acids varies from a **few to 3000 or more.**
- About **170 types of amino acids** have been found to occur in cells and tissues.
- About 25 are **constituents of proteins.**
- **Most of proteins** are however made of **20 types of amino acids.**






**FTB**

- Proteins are the **main structural components** of cell.
- Some proteins also contain P and S.
- Few proteins have Fe, I and Mg incorporated into the molecule.
- Proteins may consist of single polypeptide or more than one polypeptide.
- **Dipeptides** and **polypeptides** are formed by condensation of amino acids on the ribosome under instructions of mRNA which takes these instructions from DNA. This process is known as **translation.**
- A dipeptide has two ends; one is called **amino or -N terminal end** while other is called **carboxylic acid or -C terminal end.**
- A new amino acid can be added in this chain from its carboxylic acid or C-terminal end.

| Example | Major Functions |
|---|---|
| Building Structures | Proteins are involved in building many structures e.g. collagen, elastin, keratin and histones. |
| Enzymes | Catalyze chemical reactions and control whole metabolism of cell. |

| | |
|---|---|
| Hormones | Regulate metabolic processes. |
| Transport Proteins | Carrier protein that transports O2 (Hemoglobin), lipids, metal ions etc. |
| Antibodies | Defend the body against pathogenic attack. |
| Clotting Proteins | Prevent loss of blood after injury. |
| Mitotic Apparatus | Helps in movement of chromosomes during anaphase of cell division. |

# STRUCTURAL LEVEL OF PROTEINS

- Each protein has **specific properties** which are **determined by the number** and the **specific sequence of amino acids** in a molecule, and upon the shape which the molecule assumes as the chain folds into its inal, compact form.
- There are **four levels of organization** which are described below:

## 1. PRIMARY STRUCTURE

- The primary structure consists of **number and sequence of amino acids** in a protein molecule.
- **F. Sanger** was the first scientist who determined the sequence of amino acids in protein molecule (insulin) after ten years of his work.

Insulin → 51 Amino Acids → α chain → 21 amino acids; β chain → 30 amino acids

HB → 574 Amino Acids → α chain → 141 × 2 amino acids; β chain → 146 × 2 amino acids

- Insulin chains are held together by **disulphide bridges.**
- **Haemoglobin** is composed of **574 amino acids** in four chains.
- Two alpha chains and two beta chains.
- Each **alpha chain** contains **141 amino acids (282 in both)** and each **beta chain** contains **146 amino acids (292 in both)**
- The size of a protein molecule is determined by:
- Type of amino acids.
- Number of amino acids comprising that particular protein.



# SIGNIFICANCE OF AMINO ACID SEQUENCE

- There are over **10,000 proteins in the human body** which are composed of unique and specific sequence of **20 types of amino acids** (characteristic feature of primary structure of a protein).
- It is determined by **sequence of nucleotides in DNA.**
- The arrangement of amino acids in a protein molecule is highly specific for its proper functioning.
- Change of even single or few nucleotides in DNA (point mutation), the sequence of amino acids in protein changes and causes severe defects in body like sickle cell anaemia (hereditary disease).
- **Normal red blood cells** (disc shaped and look like doughnuts without holes in the centre) can easily cross the blood vessels while **crescent or sickle cells** cause blockage thus pain and organ damage.
- One of the best examples is sickle cell anaemia in which only one amino acid (glutamic acid) at position **6 in each beta chain** is replaced

**KPK**

In sickle cell anaemia, a person inherits two abnormal genes (one from each parent) that cause RBCs to become disc or crescent or sickle shaped.

**BTB**

- Myoglobin is another protein complex that store oxygen in the red muscles.
- Protein molecules also store energy in muscles of the body which supply energy to the body when outside source of food is inadequate like **phosphocreatin.**

by other amino acid (valine).

- Thus, haemoglobin fails to carry any or sufficient oxygen hence leading to death of patient.

**FTB**

- Primary structure is shown by all proteins at the time of their synthesis on ribosomal surface.

## SECONDARY STRUCTURE

- The polypeptide chains in a protein molecule usually don't lie flat.
- They usually coil into a helix, or into some other regular configuration.
- One of the common secondary structures is the alpha helix.
- Alpha helix involves spiral formation (helical) of basic polypeptide chain.
- Beta pleated sheet is formed by folding back of the polypeptide.
- The secondary structure is established by hydrogen bonding.

**PTB**

- The alpha helix is a very uniform geometric structure with **3.6 amino acids** in each turn of helix.
- The helical structure is kept by the formation of hydrogen bonds among amino acid molecules in successive turns of the spiral.

## TERTIARY STRUCTURE

- Usually, a polypeptide chain bends and folds upon itself forming a globular shape.
- This is the proteins' tertiary conformation.
- It is maintained by **three types of bonds:**

Tertiary structure

Ionic bond | Hydrogen bond | Disulphide bridge

- It is three-dimensional structure.

**PTB**

- In aqueous environment, the most stable tertiary confirmation is that in which hydrophobic amino acids are buried inside while hydrophilic amino acids are appeared on the surface of the molecule.

**What it means logically?**

- In an aqueous environment (water-based environment, such as inside the body), proteins fold into a tertiary structure that is most stable and energetically favorable.
- This folding follows the hydrophobic effect, which drives:
- **Hydrophobic (nonpolar)** amino acids to be buried inside the protein structure, away from water.
- Examples: Valine, Leucine, Isoleucine, Phenylalanine
- This reduces their interaction with water, increasing stability.

- **Prothrombin** is also a blood clotting protein.
- **Contractility** is one of the most outstanding property of proteins.
- **Contractile muscle proteins** (actin and myosin).
- **Tubulin of microtubule** (cilia, flagella and centrioles) help in the **movement of chromosomes** during anaphase caused by proteins (spindle fibers).

**EXTRA POINTS**

- Collagen, Actin, Fibrinogen are also examples of fibrous proteins.
- Some of the fibrous proteins may form sheet-like structures.
- Collagen is the most abundant protein in higher vertebrates found in skin, ligaments, tendons, bones and in the cornea of the eyes.
- **Globular proteins** can exist in **tertiary or quaternary** structure during function.

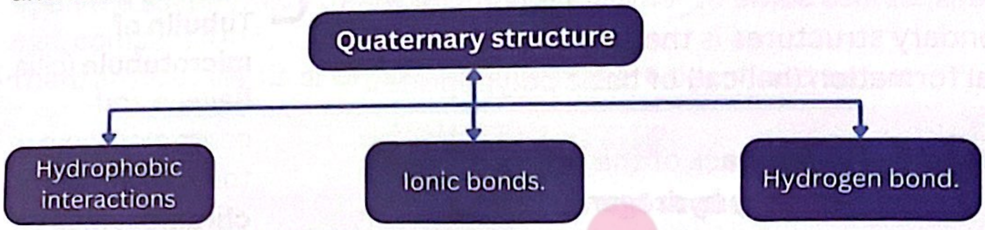
- Hydrophilic (polar) amino acids to be exposed on the outside, interacting with water.
- Examples: Serine, Threonine, Glutamine, Lysine
- These form hydrogen bonds with water, stabilizing the structure.
- This arrangement minimizes the free energy of the protein and ensures proper function and solubility in the aqueous environment.

## QUATERNARY STRUCTURE

KPK

- In plants, proteins are stored in most seeds for future need of the embryos. e.g, beans, pulses, pea etc.

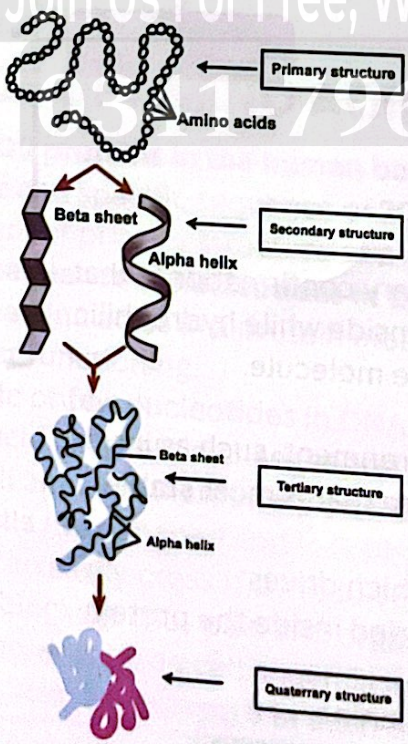
➤ In many highly complex proteins, polypeptide tertiary chains are aggregated and held together by hydrophobic interactions, hydrogen and ionic bonds.




| Feature | Primary | Secondary | Tertiary | Quaternary |
|---|---|---|---|---|
| Information | Number and sequence of amino acids in protein molecules. | Structural conformation (form or shape) e.g. coil or helix | Bending and folding of polypeptide chain and forming regular 3-D globular shape. | Two or more chains aggregate and help together by hydrophobic interactions. |
| Bonds | Peptide bond | Hydrogen | Ionic, Hydrogen, Disulphide bridges | Hydrogen, Ionic bonds, Hydrophobic interactions. |
| Example | Insulin | Alpha helix (α-helix), β-pleated sheet | Human myoglobin | Hemoglobin |



➤ Haemoglobin is of quaternary structure.



# CLASSIFICATION OF PROTEINS

➤ According to their structure, proteins are classified as:

| Fibrous | Globular |
|---|---|
| 1. Consists of one or more polypeptide chains linearly arranged in the form of fibrils. | 1. Spherical or ellipsoid in shape due to multiple folding of the Polypeptide chains. |
| 2. Insoluble in aqueous media. | 2. Soluble in aqueous media such as salt solution, solution of acids and bases, or aq. Alc. |
| 3. Elastic and non-crystalline | 3. Non elastic and crystalline |
| 4. Secondary structure is most important in them. | 4. Tertiary structure is most important in them. |
| 5. They perform structural roles in cells and organisms. | 5. They disorganize with changes in physical and physiological environment. |
| 6. **Examples:**<br>• Silk fibre (from silk worm, spider's web)<br>• Myosin (in muscle cells)<br>• Fibrin (blood clotting)<br>• Keratin (of nails, hairs, hooves, feathers), ligament, tendon etc. | 6. **Examples:**<br>• Enzymes<br>• Hormones<br>• Antibodies<br>• Haemoglobin<br>• Albumen of egg<br>• Proteins of cell membrane |

# ROLE OF PROTEINS

➤ Proteins play both structural and functional roles as follow:

| Structural roles | Functional roles |
|---|---|
| 1. Collagen (it establishes the matrix of bone and cartilage) | 1. Enzymes (control metabolism) |
| 2. Elastin (it provides support for connective tissues such as tendons and ligaments) | 2. Hormones (regulate metabolism or physiological activities) |
| 3. Keratin (It strengthens protective covering like hair, nails, quills, horns, feather and beaks etc) | 3. Antibodies (produced by WBCs in response to antigens and provide immunity) |
| 4. Histone (It arranges the DNA into the chromosome) | 4. Haemoglobin (found in RBCs and transports oxygen mainly and to some extent CO2 also).<br>5. Fibrinogen (blood clotting) found in blood plasma.<br>6. Oval albumin (egg white) and casein (milk-based protein) both are involved in storage of amino acids. |



**PTB**

- Some proteins (e.g. Haemoglobin) work as carriers and transports specific substances such as oxygen, lipids and metal ions etc.
- Movement of organs and organisms, and **movement of chromosomes during anaphase** of cell division, are caused by proteins.

# LIPIDS

➤ **Heterogenous group of organic compounds** related to fatty acids.

**STB**

- Stearin is found in beef and mutton.
- Bloor first proposed term lipids in **1943**.
- Linolin ($C_{57}H_{104}O_6$) is found in cotton seed have linoleic acid.

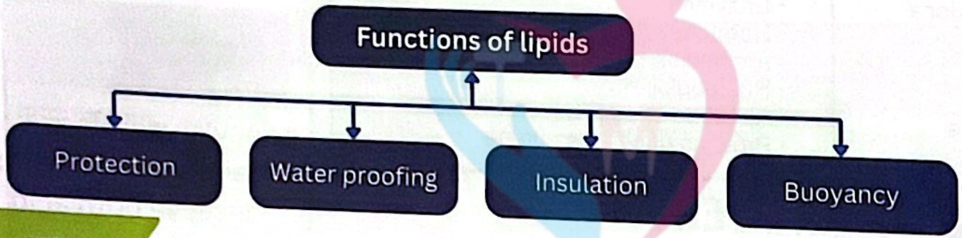
**BTB**

- Acylglycerols are called neutral lipids because both acid and base are present in them.
- After esterification, there are no free carboxyl (-COOH) or hydroxyl (-OH) groups left to ionize, making the molecule uncharged (neutral).

**KPK**

- During formation of triglycerides, three water molecules are released and process is called condensation.
- Triglycerides are stored in animals as fats.
- Most of the fatty acids in cell contain **16-18 carbons** per molecule.

- The collective name for variety of organic compounds such as fats, oils, waxes, and fat-like mdecules (steroids) found in the body.
- They contain **carbon**, **hydrogen** and **oxygen** other elements such as **nitrogen** and **phosphorus** may also be present in lipids.
- Most lipids are **non-polar.**
- As they are non-polar molecules, most lipids are insoluble in water but soluble in non-polar organic solvents like alcohol, acetone, chloroform, ether, benzene etc.
- The percentage of oxygen in lipids is less than the carbohydrates which makes lipids lighter and make it much less soluble in water than most carbohydrates.
- Because of **high proportion of C-H bonds** and very low proportion of oxygen, lipids **store doubles the amount of energy** as compared to the amount of any carbohydrate.
- Due to hydrophobic properties, lipids are **components of cellular membranes** (phospholipids and cholestrol), act as compounds energy stores/energy storing (triglycerides), etc.

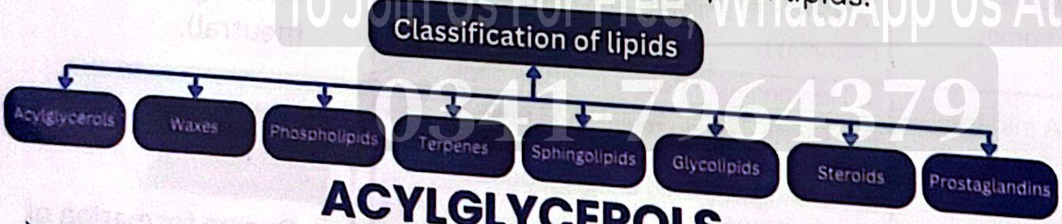



**PTB**

- Waxes, in the exoskeleton of insects, and cutin, an additional protective layer on the cuticle of epidermis of some plant organs eg. leaves, fruits, seeds, etc., are some of the main examples.

## CLASSIFICATION OF LIPIDS

- Lipids are classified based on solubility and the products obtained upon hydrolysis. There are following main groups of lipids.




## ACYLGLYCEROLS

- Chemically, they can be defined as esters of fatty acids and alcohol, the reaction is called esterification.
- Acylglycerols = glycerol + fatty acids
- Most widely spread acylglycerols is the triacylglycerol also called as triglycerides or neutral lipids.
- An ester is the compound produced as the result of a chemical reaction of an alcohol with an acid and a water molecule is released as shown below:

$$\underset{\text{alcohol}}{C_2H_5OH} + \underset{\text{acetic acid}}{HOOCCH_3} \longrightarrow \underset{\text{an ester}}{C_2H_5OCOCH_3} + H_20$$

**INFORMATION**

- Ghee with saturated fatty acids is prepared from vegetable oil by passing hydrogen through it.
- Intake of ghee should be minimized as it may store in blood vessels reducing their flow capacity increasing risk of heart attack.

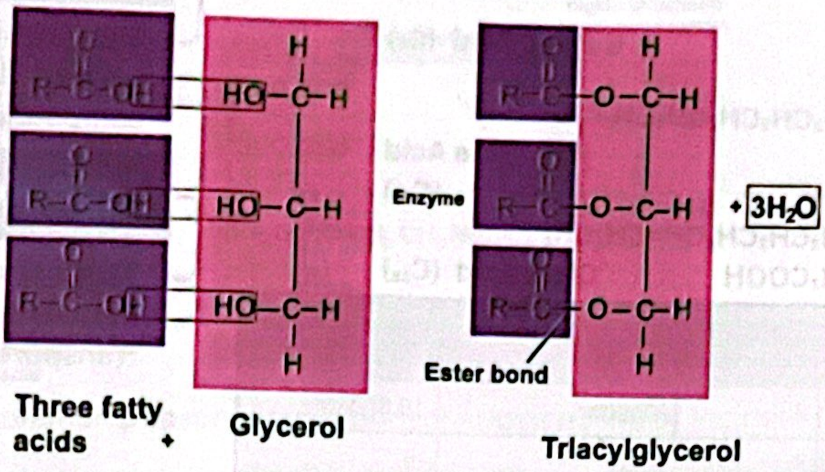
**KPK**

- Oleic acid is stored in plant seeds.
- The triglycerides have high calorific value and usually yield twice as much energy as per gram as that of carbohydrate.

**BTB**

- **1g Carbohydrate** gives **4.1 kcal** energy.
- **1g of Proteins** gives **4.6 kcal** energy.
- **1g of Lipids** gives **9 kcal energy.**

- OH is released from alcohol and H from an acid.
- H and OH combine and form a water molecule.




- Hydroxyl group is polar in nature therefore glycerol is soluble in water.

## FATTY ACIDS

- Most important component of triglycerides.
- It is a type of organic compound containing one carboxylic acid group attached to a hydrocarbon.
- Each fatty acid is represented as RCOOH, where R is hydrocarbon tail.
- Solubility of fatty acid in organic solvents, melting points and their hydrophobic nature increase with the increasing number of carbon atoms in the chain.

| Saturated fatty acid | Unsaturated fatty acid |
|---|---|
| 1. C–C bond | 1. Upto six C=C bond. |
| 2. Straight chain | 2. Ring or branched |
| 3. Solid at room temperature (high melting point) | 3. Liquid at room temperature (low melting point) |
| 4. Fats | 4. Oils |
| 5. Found in animals | 5. Found in Plants |
| 6. Have more energy | 6. Have less energy |



### PTB

- Fatty acids contain **even number (2-30) of carbon atoms** in a straight chain attached with hydrogen and have an acidic group (carboxylic group)
- They are **not crystalline** but can be crystallized under specific conditions.
- They are **Hydrophobic compounds.**
- Fats & oils are lighter than **$H_2O$** and have a **specific gravity of 0.8.**
- Palmitic acid **(C16)** is much more soluble in organic solvent than butyric acid **(C4)**
- The melting point of palmitic acid is **63.1°C** as against **-8°C** for butyric acid.
- Oleic acid is unsaturated fatty acid (double bond is present between **C9 and C10**).

2 1
$CH_3COOH$ — Acetic Acid ($C_2$)

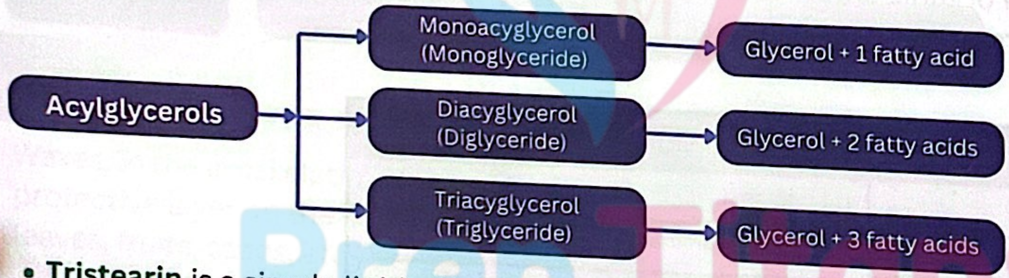
4 3 2 1
$CH_3CH_2CH_2COOH$ — Butyric Acid ($C_4$)

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2$
$CH_2CH_2CH_2CH_2COOH$ — Palmitate Acid ($C_{16}$)

10 9
$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH{=}CH.CH_2$
$CH_2CH_2CH_2CH_2CH_2CH_2COOH$ — Oleic Acid ($C_{18}$)

| Fatty acid | Type | No. of Carbon | Source | Melting Point |
|---|---|---|---|---|
| Acetic acid | Saturated | 2 | Vinegar | 16.6°C |
| Butyric acid | Saturated | 4 | Butter | -8°C |
| Palmitic acid | Saturated | 16 | Palm tree | 63.1°C |
| Stearic acid | Saturated | 18 | Most fats and oils | 70°C |
| Oleic acid | Mono-unsaturated | 18 | Olives | 1°C |
| Linoleic acid | Poly-unsaturated | 18 | Vegetable oils | -5°C |

**FTB**




- **Tristearin** is a simple lipid which shows molecular formula as $C_{57}H_{110}O_6$. Acylglycerols are the most abundant lipids in living organisms.
- About **30 different fatty acids** are found.
- Fatty acids vary in length. Acetic acid (**C2**) and butyric acids (**C4**) are the
- simplest fatty acid. Palmitic acid (**C16**) and stearic acid (**C18**) are the most common fatty
- acids. Typical source of palmitic and stearic acid is most fats and oils.
- There melting point is **63°C** and **70°C** respectively.
- Oleic acid (**C18**) is found in olive oil having melting point **4°C**.
- Linoleic acid (**C18 with 2 double bonds**) is found in vegetable oil having melting point **-5°C**.

**BTB**

- Phospholipids a[re] amphiphilic compounds.

**STB**

- They regulate ce[ll] permeability and transport proces[s]

## PHOSPHOLIPIDS

- Phospholipids are derivatives of **phosphatidic acid.**
- Phospholipids are composed of Glycerol, Fatty acids and Phosphoric acids.
- Nitrogenous bases are important components of phospholipids.
- A phospholipid is formed when phosphatidic acid combines with one of the four organic compounds such as **choline** (a nitrogenous base), **ethanolamine** (an amino alcohol), **inositol** (an amino alcohol) and

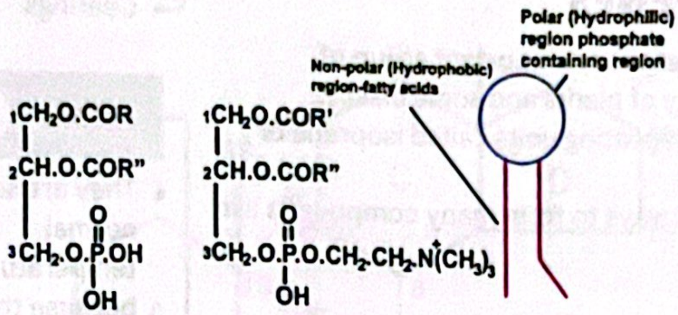
**KPK**

- Terpenoids are lipids that like t[he] steroids do not contain fatty a[cids]

**STB**

- Terpenes help [in] oxidation-redu[ction] reactions.

serine (an amino acid).




phosphatidic acid | phosphatidylcholine (Lecithin) | Phospholipid molecule

- Most common phospholipid is phosphatidylcholine or lecithin.

**Composition of lecithin**
- Glycerol → In backbone
- 2 fatty acids → At $C_1$ and $C_2$
- Phosphoric acid → On $C_3$ of glycerol
- Nitrogenous base (choline) → Attached to phosphoric acid

- Phospholipid molecule contains two parts.
- **3 fatty acids**+1 glycerol =triglycerides.
- **2fatty acids** +1glycerol+phosphate group=phosphatidic acid
- **2fatty acids**+1glycerol=phosphate group+N-base=phospholipids.
- Phospholipids are the major constituent of lipid bilayer of cell membrane.
- They arrange themselves in a double layer in the presence of water in the plasma membranes of cell.



**Parts of phospholipid**
- Polar head
  - Hydrophilic (polar, Water soluble)
  - Phosphate region
- Two non-polar tails
  - Hydrophobic (Nonpolar, Water insoluble)
  - Contain fatty acids



**PTB**

- They are widespread in bacteria, animal, and plant cells and are frequently associated with membranes.

**FTB**

- They are complex or compound lipids.
- Phosphatidic acid molecule is most similar to diglyceride that it contains a glycerol and a phosphate group esterified with first and second OH group of glycerol and phosphate group esterified with third OH group of glycerol.

**BTB**

- Steroids are organic molecules and are included in lipids due to their similarities with other lipids.
- They are **non fatty acids lipids.**
- Hundreds of steroids are found in plants, animals and fungi.
- All steroids are manufactured in cells.
- Steroids play very important functions in the body.
- Sex hormones like estrogen, progesterone in female and testosterone in male are steroids in nature.
- Vitamin D which regulates calcium metabolism and bile salts which emulsify fats are steroids.

**STB**

- Formula of wax is $CH_3(CH_2)_4COO(CH_2)_{29}CH_3$.
- Waxes are water repellent.

**BTB**

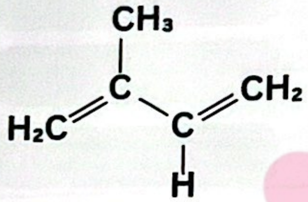
- Most common animal wax is bee's wax and plant wax is epicuticular wax.
- Waxes are used in making:
- Plastics

## TERPENES

- Terpenes/ terpenoids are a very large and important group of compounds produced by a variety of plants and some insects.
- Terpenes are made up of simple repeating units called isoprene or isoprenoid units.
- These units condense in different ways to form many compounds like rubber, carotenoids, steroids etc.

**FTB**

- Terpenes are derived lipids.
- Isoprene unit is a 5-carbon unsaturated compound ($C_5H_8$) (**2-Methyl-1,3-butadiene**)




| Terpenes | Examples |
|---|---|
| Monoterpenes (2 isoprene units) | Menthol |
| Diterpene (4 isoprene units) | Vitamin A, phytol (chlorophyll tail) |
| Triterpene (6 isoprene units) | Ambrein |
| Polyterpene | Natural rubber |

**PTB**

- Lipids constitute major source of energy and play an important role in the structure of membranes of the cell and of organelles found in the cell.
- They also provide insulation, mechanical protection and protection from water loss and abrasive damage.



## STEROIDS

- Steroids are composed of **17 carbon atoms** arranged in **4 interlocked rings** in which **3** are of **6 carbons** and **1 contains 5 carbons.**
- Cholesterol is the structural component of cell membrane and brain tissue.
- Cholesterol is precursor of a large number of equally important steroids which include bile salts, male sex hormone testosterone, oestrogen etc.

**FTB**

- Steroids are lipids of highly molecular weight.
- They can be crystallized.
- The length and structure of the side chains that extend from these rings distinguish one steroid from other steroids.
- They are synthesized from isoprene units.

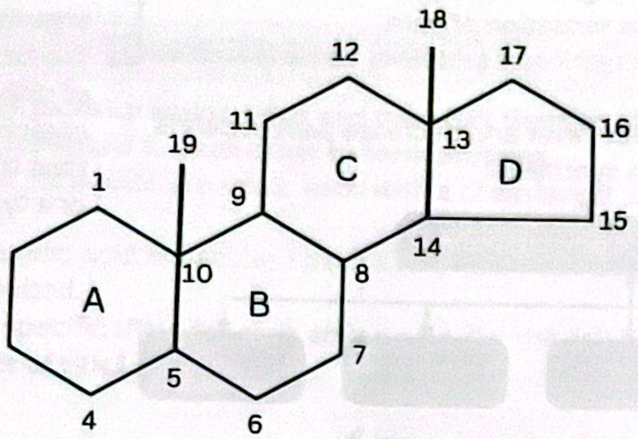
- Candles
- Coatings

**KPK**

- They are solid at normal temperature because they have a high melting point.
- They are stable compound and are resistant to degradation.

**BTB**

- The name prostaglandin is derived from prostate gland because it was first isolated from seminal fluid in **1935**.
- It was believed to be part of prostatic secretions.
- They are group of physiologically active lipid compounds having diverse hormone-like effects in animals.
- They are derived enzymatically from fatty acids.
- Every prostaglandin contains **20 carbon** atoms including **5 rings.**
- In **1971** it was discovered that aspirin like drugs could inhibit the synthesis of prostaglandin.
- They play a role i




- dilation and contraction in smooth muscle cells.
- They cause aggregation and disaggregation of platelets, regulate inflammation, regulate hormones, control cell growth.
- They sensitize spinal neuron for pain.
- Act on Thermoregulatory centre of hypothalamus to regulate fever.

## WAXES

- Waxes are widespread as protective coatings on fruits and leaves.
- Waxes are mixtures of long chain alkanes (with odd number of carbon atoms ranging from $C_{25}$-$C_{35}$) and alcohols, aldehydes, ketones and esters of long chain fatty acids.

**PTB**

- Some insects also secrete wax
- Waxes protect plants from water loss and abrasive damage.
- They also provide water barrier for insects, birds and animals such as sheep.

**FTB**

- They are highly hydrophobic hydrocarbons.
- There are two types of waxes:

| Natural | Synthetic |
|---|---|
| 1. They are simple lipids. | 1. These are generally derived from petroleum or polyethylene. |
| 2. They are typical esters of long chain fatty acids and long chain alcohols. • Bees wax found in honeycomb. • Cutin found on surface of plants (leaves and fruits). • Lanolin found from sheep wool. • Suberin found in cell wall of endodermis of plant roots. 3. They are chemically inert and resistant to atmospheric oxidation. | 2. Paraffin wax is used to make candles, waxpaper, lubricants and sealing material. |

**BTB**

- In some animals and all plant viruses, RNA functions as hereditary material.
- The amount of RNA varies from cell to cell.
- About **97%** of transcriptional output is non protein coding in eukaryotes.
- So, they are called **noncoding RNA (ncRNA).**

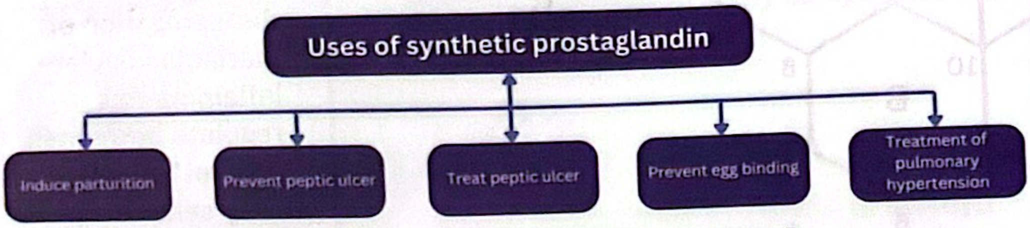
**BTB**

- The **rRNA** is the **catalytic component of ribosome.**
- It is synthesized by the genes on DNA of several chromosomes found within the region of nucleus

## PROSTAGLANDINS

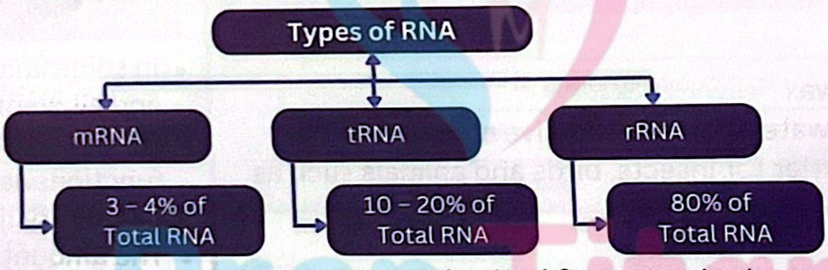
- They exist in virtually every mammalian tissue, acting as local hormone.
- They are derived from arachidonic acid.
- Their function varies widely depending on the tissues
- Some reduce blood pressure whereas others raise it.

- In the immune system various prostaglandins help to induce fever and inflammation and also intensify the sensation of pain.
- They also help to regulate the aggregation of platelets, an early step in the formation of blood clots.
- Infact the ability of aspirin to reduce fever and decrease pain depends on the inhibition of prostaglandins synthesis.




# RNA (RIBONUCLEIC ACID)

- Like DNA, RNA is a polymer of ribonucleotides.
- The RNA molecule occurs as a single strand, which may be folded back on itself, to give a double helical characteristic (like hair pin loops).
- Nitrogenous bases form the usual complementary pairing viz. cytosine(C) with guanine(G) and uracil(U) with adenine(A).
- RNA is synthesized by DNA in a process called transcription.




- All these three types of RNAs are synthesized from DNA in the nucleus and then are moved out in the cytoplasm to perform their specific functions.

## MESSENGER RNA (MRNA)

- This type of RNA consists of a single strand of variable length.
- Its length depends upon the size of the gene as well as the protein for which it is taking the message.
- For example, for a protein molecule of **1,000 amino acids,** mRNA will have the length of **3,000 nucleotides.**
- Messenger RNA carries the **genetic information from DNA (nucleus) to ribosomes in cytoplasm,** where amino acids are arranged according to the information in mRNA to form **specific protein molecule.** This process is known as **translation.**

## RIBOSOMAL RNA (rRNA)

- Ribosomes consist of rRNA and protein. rRNA is transcribed by the genes present on the DNA of several chromosomes.
- It is called **rRNA** because it eventually becomes part of the ribosome.
- The rRNA is packaged with a variety of proteins into ribosomal subunits.
- It is the major portion of RNA in the cell and may be up to **80%** of the total RNA.

called nuclear organizer.

- The base sequence of rRNA of all organisms is similar thus there is only one type of rRNA.

- It acts as a machinery for the synthesis of proteins.

## TRANSFER RNA (tRNA)

- **Transfer RNA picks up amino acids and transfers them to ribosomes, where they are linked to each other to form proteins.**
- Transfer RNA molecules are small, each with a chain length of **75 to 90** nucleotides.
- It transfers amino acid molecules to the site where peptide chains are being synthesized.
- There is one specific tRNA for each amino acid. So, the cell will have at least **20 kinds of tRNA molecules.**

**KPK**

- A eukaryotic chromosome is basically a nucleoprotein that is formed by the DNA and protein.
- Nucleoproteins are slightly acidic and soluble in water.
- Glycoproteins are also present in the egg albumin

**FTB**

## MESSENGER RNA (mRNA)

- Every three nucleotides in mRNA encode a specific amino acid, such triplets of nucleotides along the length of the mRNA are called **codons** of **genetic codes.**

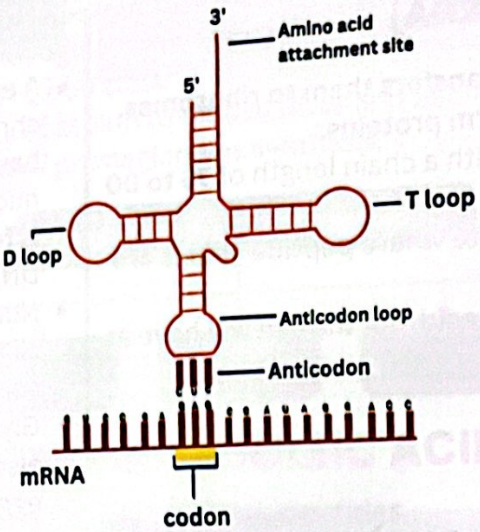
## RIBOSOMAL RNA (rRNA)

- The basic sequence of rRNA is similar from bacteria to higher plants and animals.
- rRNA have the largest size among the RNA.

## TRANSFER RNA (tRNA)

- A tRNA is a single stranded molecule but it shows a duplex appearance at its some regions where complementary bases are bonded to one another.
- It shows a **flat cloverleaf shape** in two dimensional views.
- Its **5' end** always **terminates in Guanine base** while the **3' end** is always terminated with base sequence of **CCA.**
- Amino acid is attached to tRNA at this end.
- The nucleotide sequence of the rest of the molecule is variable.
- tRNA has **three loops.** The **middle loop** in all the tRNA is composed of 7 bases, the middle three of which form the anticodon.
- It is complementary to specific codon of mRNA.
- The **D loop** recognizes the activation enzyme.
- **Theta (θ) loop** recognizes the specific place on the ribosome for binding during protein synthesis.
- Sixty tRNA have been identified. However, human cells contain about **45 different kinds of tRNA molecules.**
- RNA is usually degraded within your cells in **30 minutes.**

tRNA




**PTB**

- It is strongly associated with the ribosomal protein **where 40 to 50%** of it is present.
- On the surface of the ribosome the mRNA and tRNA molecules interact to translate the information from genes into a specific protein.
- Transfer RNA picks up amino acids and transfers them to ribosomes, where they are linked to each other to form proteins.

| Feature | mRNA | tRNA | rRNA |
|---|---|---|---|
| Function | Take message from DNA to ribosomes | Transfer amino acids to ribosomes | Formation of ribosomes |
| Length | Single strand of variable length | Length of 75-90 nucleotides | Double helix with constant length |
| Percentage | 3-4% | 10-20% | 80% |

## CONJUGATED MOLECULES

- Two different molecules, belonging to different categories, usually combine together to form conjugated molecules.

Conjugated molecules
- Glycocolipids
- Glycoproteins
- Lipoproteins
- Nucleoproteins

- **Glycolipids** are complex lipids containing one or more simple sugars in connection with long fatty acids or alcohol.
- Glycolipids are present in white matter of brain and myelin sheath of nerve fibers and chloroplast membrane.
- **Glycoproteins** are formed when proteins are covalently attached to carbohydrates.
- Glycoproteins are widely distributed in the cells.
- They function as hormones, transport proteins, structured proteins and receptors.
- The blood group antigens contain glycoproteins, which also play an important role in blood grouping.
- **Lipoproteins** are formed by the combination of protein with

phospholipids.

- Phospholipid protein complexes are widely distributed in plant and animal materials.
- They occur in milk, blood, cell nucleus, egg, yolk membrane and chloroplast.
- Nucleic acids have special afinity for basic proteins. They are combined to form **nucleoproteins.**
- They are **found** in chromosomes and ribosomes.

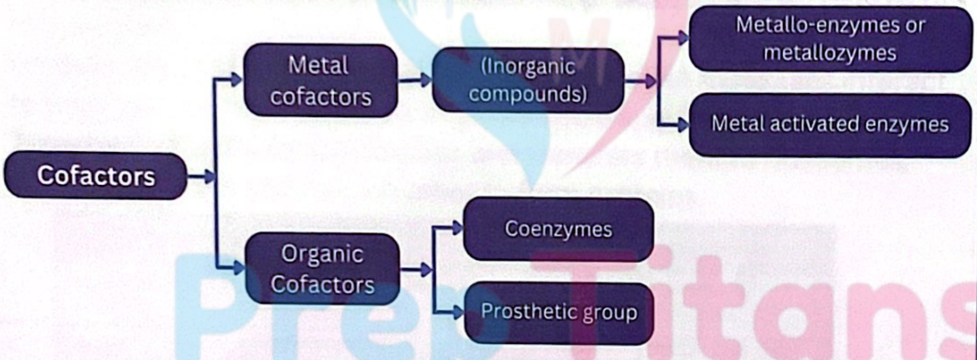
**PTB**

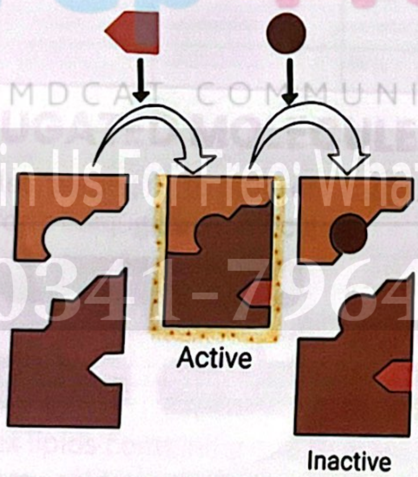
- Most of the cellular secretions are glycoprotein in nature.
- Both glycoproteins and glycolipids are integral structural components of plasma membranes.
- Lipoprotein formed by combination of lipids and proteins are basic structural framework of all types of membranes in the cells.
- The nucleohistones are present in chromosomes. These conjugated proteins are not only of structural but also are of functional significance. They play an important role in regulation of **gene expression.**

# ENZYMES

## Introduction

- Enzymes are biological catalysts.
- They enhance speed of reaction without being themselves consumed.
- Sum of all the chemical reactions take place in a cell called **metabolism.**
- Enzymes catalyse these metabolic reactions.
- Mostly enzymes are made of proteins and **coded by genes.**
- The substance on which enzyme acts is called **substrate.**
- Enzymes requires a non-protein part for their proper functioning called **cofactor.**
- Some enzymes are solely composed of proteins e.g. lipase, pepsin.
- Majority of enzymes which are proteins in nature can have molecular weight ranging from about **10,000** to over **1M.**
- Such enzymes have tertiary or quaternary structure.






### CO-ENZYME

- If non-protein part is attached loosely to enzyme, it is called **co-enzyme.**
- **NAD⁺**, **FAD⁺**, **NADP**, **ATP** are the co-enzymes.
- Coenzymes are mostly derived from vitamins & minerals.
- Only small quantity of vitamins is needed because like enzymes co-enzymes can be used again and again. They are also detachable co-factors.

**Ethyl alcohol** $\xrightarrow{\text{Alcohol dehydrogenase + NAD}^+}$ **Acetaldehyde + NADH$_2$**

**BTB**

- The word enzy[me] was coined fro[m] Greek word **"levened"** or "i[n] **yeast".**
- First enzyme wa[s] discovered by P[ayen] **and Persoz** fro[m] germinating bar[ley] seeds in **1833** a[nd] named it diasta[se].
- The term enzym[e] was introduced [in] **1877** by **Wilhelm Kuhne.**
- Enzymes can be defined as **thermolabile biocatalyst.**
- Enzymes can w[ork] inside or outsid[e] the cell.
- Ribozyme is fou[nd] in ribosome.
- These are not proteins in fact catalytic RNA molecules.
- It controls polypeptide elongation duri[ng] protein synthes[is] such as **peptidy[l] transferase.**
- Enzymes form a colloidal suspension in cytosol thus, at lower temperat[ure] enzymes activity stops or decreas[es].
- At high temperature, during fever, enzyme denatur[es]

## PROSTHETIC GROUP

- If non-protein part is attached covalently, it is called **prosthetic group.**
- It is permanently attached to enzymes and does not detach after the completion of reaction.
- An iron containing porphyrin ring attached to some enzymes like cytochromes is an example of prosthetic group.

## ACTIVATOR

- If non-protein is metal ion like **$Mg^{++}$, $Zn^{++}$** etc.
- These are detachable inorganic co-factor.

$$\text{Glucose + ATP} \xrightarrow{\text{Hexokinase} + Mg^{+2}} \text{Glucose-6-phosphate + ADP}$$

- Apoenzyme
  - Only protein part
  - Non-active
- Holoenzyme
  - Apoenzyme + non-protein part
  - Active enzyme

- Enzymes and coenzymes are used again and again after the reaction and remain unchanged at the end of reaction.
- Enzyme for integral for synthesis of proteins are integral part of ribosomes.

### PTB

- Catalytic activity of enzyme is restricted to small portion called active site.
- Substrate attaches to the active site made of only a few amino acids while rest of bulk of amino acids maintains globular structure.
- Enzymes are made of **hundreds of amino acids.**
- They have **three-dimensional globular structure** that has specific chemical composition due to its component amino acids and a specific shape.
- **Cofactor** acts as a bridge between enzymes and substrate.
- It contributes directly to the chemical reactions which bring about catalysis.
- Sometimes the co-factor provides a source of chemical energy, helping to drive reactions which would otherwise be difficult or impossible.
- Enzymes may be dissolved in cytoplasm or attached organelles.
- They are produced by living cells for use in or near site of production.

### FTB

- Enzyme molecules are made of protein are mostly made of protein and some are called **ribozymes** made of RNA molecule found in ribosomes.
- Substrate molecule is attached to the active site by **non-covalent interactions** like H-Bonding and hydrophobic interactions.
- Final shape of active site is formed after the attachment of co-factor.
- Enzyme increases efficiency of the reaction up to **$10^{20}$ times.**

- **Dalton (Da): It is very small unified atomic mass unit.**
- In Biology, **One hydrogen atom = One Da.**
- The molecular weight of proteins and other macromolecules are measured in **Kilo-Dalton (kDa)**
- Enzymes are of high molecular weight.
- Molecular weight of peroxidase = **40,000 Daltons**
- Molecular weight of catalase = **250,000 Daltons or 250 kDa.**

### KPK

- Molecular geometry is very important in enzyme action mechanism.
- Beyond enzyme's active site, rest of enzyme is called **framework.**

### BTB

- Tertiary structure of a protein or any other macro-molecule play important role in their proper functioning.
- The simple protein consists of only one long polypeptide chain e.g. ribo-nuclease consists of **124 amino acids.**

- Active site of enzyme is made of **3 – 12 amino acids** which may be scattered in the polypeptide but are brought together in a a particular fashion due to secondary and tertiary folding of the polypeptide chain.
- Active site for **aldolase** consists of glycine, histidine and alanine amino acids.
- Bulk of amino acids maintain the shape.

Bond in Substrate to be broken → Bond Stretched by enzyme → More likely to break.

## CHARACTERISTICS OF ENZYME

- Increase the speed of reaction.
- Required in small quantity.
- Highly sensitive to pH and temperature and substrate concentration.
- Work in vivo as well as in vitro (glassware).
- Highly specific in its function or slightly less specific.
- Sometimes requires cofactor for proper functioning.
- Lower the activation energy of the reactions.
- Do not effect affect the equilibrium of the reaction.

**PTB**

- All enzymes are globular proteins.
- Their presence does not affect nature or properties of the end products.
- Some enzymes are potentially damaging if they are manufactured in their active form.
- For example, pepsin is a powerful protein - digesting enzyme and is quite capable of destroying cell's internal structure and thus is produced in **inactive pepsinogen** form by the cell.
- It is converted in its active form only in the digestive tract where it is required to be active.

**FTB**

- Inactive pepsinogen has an additional polypeptide fragment attached to its active site which doesn't allow the binding of the substrate.
- When pepsinogen is exposed in HCl (as in stomach cavity) the additional polypeptide fragment is removed as a result it become active.

## MECHANISM OF ENZYME ACTION

- Every enzyme by virtue of its specificity recognizes and reacts with specific reactant.

Enzyme + substrate → ES complex → Enzyme + product

- The enzyme can make the local conditions inside the active site quite different from those outside, such as pH, $H_2O$ concentration, and charge, so that the reaction is more likely to happen.
- Activity of enzymes in a cell can be regulated by its products. When the activity of an enzyme is inhibited by its own product, it is called

**BTB**

- Catalytic site is composed of **2-12 amino acids.**
- Enzymes are very efficient.
- One enzyme can catalyse **100,000** substrates in one second.
- This is called **turn over number.**

**TURN OVER UNIT**

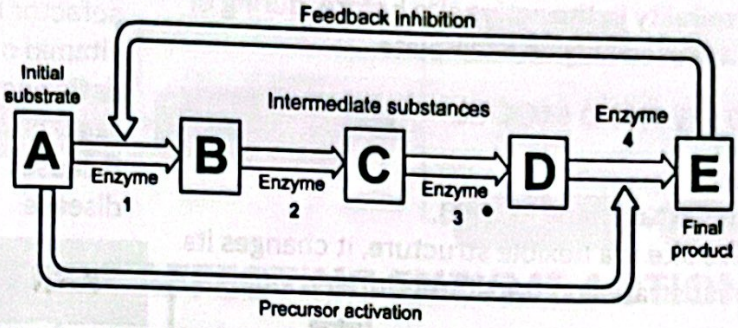
- If you turn something over or if you turn it over, it is moved so that the top part is now facing downward change or reversal of position
- Enzymes need aqueous environment.
- That's why; we feel thirst after taking meal.
- Enzymes need specific temperature for their proper functioning.
- So, drinking cold drink, cold water during meal is medically wrong.

**KPK**

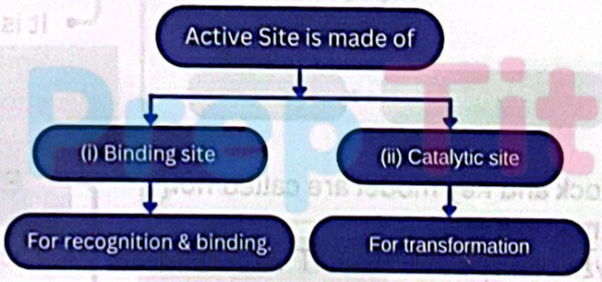
- Enzyme lower the activation energy, by stabilizing the transition state. **$2H_2O_2 \rightarrow 2H_2O + O_2$** **$\Delta H = +86\ kJ\ mol^{-1}$**
- This reaction occurs at **1 kJ mol$^{-1}$** in the presence of

feedback inhibition or end product inhibition.

- Similarly, increase in concentration of substrate can cause increase in rate of reaction.
- This activation is called **precursor activation.**

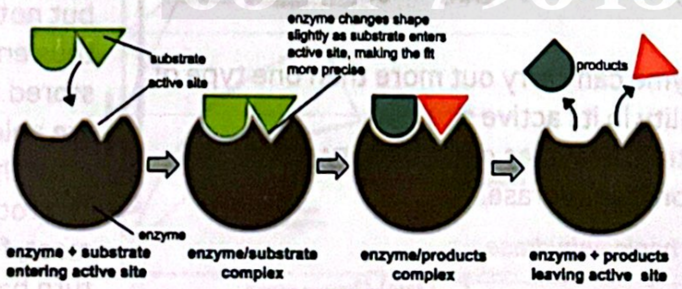



- Typically, feedback loop can be divided into two main types: positive feedback loops, in which a change in each direction causes additional change in the same direction, and negative feedback loops, in which a change in a given direction causes change in the opposite direction.
- **Active Site:**
- An enzyme and its substrate react with each other through a definite charge-bearing site of an enzyme called active site.
- The charge and shape of the active site is formed by some amino acids present in the polypeptide chain of the active site of the enzyme.
- These amino acids are brought closer and are arranged in a specific way by coiling and folding of the polypeptide chain within the globular symmetry of the enzyme.




## LOCK AND KEY MODEL

- Substrate and enzyme has specific shape that can't be altered.
- Specificity of enzyme explained by this model.
- This model is proposed by **Emil Fischer in 1890 (PTB)** or **1894 (FTB).**




## SPECIFICITY OF ENZYME

- Specificity of enzyme due to their specific three-dimensional structures.
- According to this model, like a specific key can open specific lock.
- Likewise, specific substrate can be transformed into product.

enzyme

- Cofactor is on - off switch for activating enzyme.
- Absence of cofactor leads to vitamin or mineral deficiency disease like lack of vitamin B causes beriberi disease.

**KPK**

- Induced fit model suggests that enzymes molecules are in in-active form. To become active, they undergo slight changes in their structure to more specifically accommodate the substrate.
- It is said to **'induced to fit'** the substrate.

**BTB**

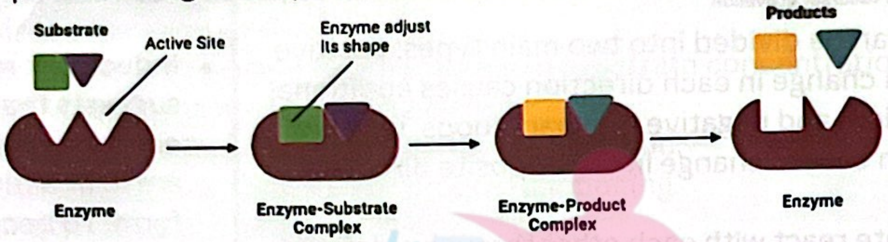
- **Luciferase** is an enzyme in fruit flies responsible for light production.
- Enzymes are denatured by heat but not by cold thus enzymes stored in below **0°C** are able to function after thawing.
- The foods like meat, fruits may turn bad due to their enzyme activity therefore they are advised to be kept in the refrigerator.

**PTB**

- According to lock and key model!
  "***Active site is a rigid structure and specific***"
- There is no modification or flexibility in the active site before, during or after the enzyme action and it is used only as a template.

## INDUCED FIT INTO MODEL

- This is more acceptable model.
- This model is proposed by **Daniel Koshland** in **1959**.
- According to this model, active site is a flexible structure, it changes its shape according to shape of substrate and transforms into product.




**FTB**

According to lock and Model: → Substrate → Lock; Enzyme → Key

- Active site acts as a template.
- Enzymes work that according to lock and Key model are called **non-regulatory** enzymes like sucrase, maltase etc.
- The ability of an enzyme to catalyze one specific reaction is perhaps its most significant property.
- When an enzyme can catalyse only one substrate it is called **absolute specificity e.g. urease.**

$$\underset{\text{Urea}}{H_2N-\overset{\overset{\Large O}{\|}}{C}-NH_2} + H_2O \xrightarrow{\text{Urease}} 2NH_3 + CO_2$$

- According to Koshland, an enzyme can carry out more than one type of related reactions due to flexibility in its active site.
- Such enzymes are called **allosteric enzymes or regulatory enzymes.**
- For example, hexokinase, carbonic anhydrase.

$$Hb + 4O_2 \xrightarrow{\text{carbonic anhydrase}} Hb_4O_2$$

$$CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} H_2CO_3$$

$$H_2CO_3 \xrightarrow{\text{carbonic anhydrase}} H^+ + HCO_3^-$$

enzyme
- Cofactor is on - off switch for activating enzyme
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**KPK**

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**BTB**

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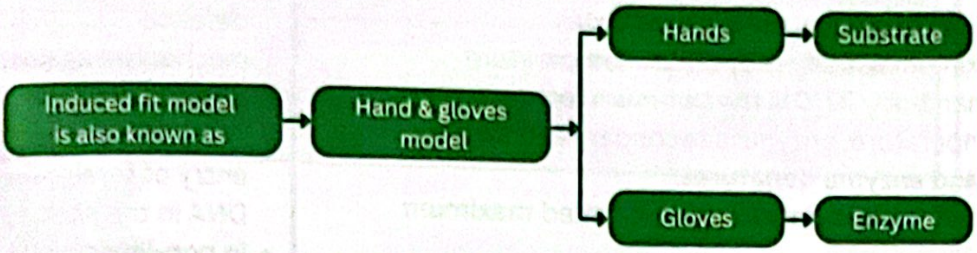
- The foods like meat, fruits may turn bad due to their enzyme activity therefore they are advised to be kept in the refrigerator.

- All these reactions occur in the presence of enzymes carbonic anhydrase.
- Enzymes are inactive and to become active enzyme most undergo slight conformational changes in structure to accommodate the substrate.

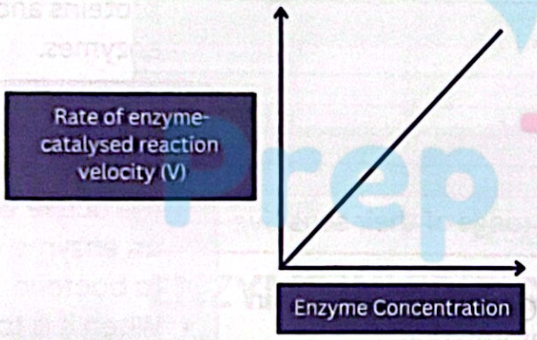



## FACTORS AFFECTING ENZYME ACTION

- Specificity of enzyme is due to its specific chemistry or its surface configuration.
- Any factor that can alter chemistry & shape of enzyme can affect its action.

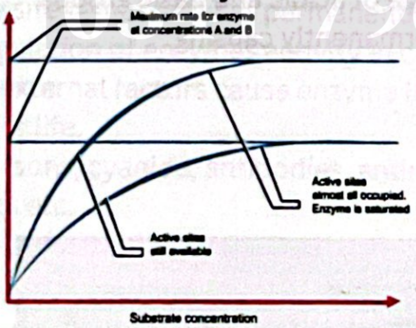
### ENZYME CONCENTRATION

- If enzyme concentration is unlimited, the rate of reaction becomes directly proportional to enzyme concentration.
- By increasing concentration of enzyme, number of active sites are increased and rate is increased.
- This effect persists till the equilibrium state.




### SUBSTRATE CONCENTRATION

- Enzyme concentration is maintained at a high level, the substrate concentration increases the velocity of reaction at first.




- Reaction reaches a maximum velocity at the equilibrium.
- The rise in velocity decreases progressively with further increase in substrate.
- This happens when all the active sites are being occupied.
- No enzyme is left free active site.
- This point known as saturation point.

**KPK**

- Enzymes present in mammals work best at 40°C.
- Enzymes of arctic snow flea work at -10°C.
- In thermophilic bacteria enzymes work at 90°C.
- The increase in rate with temperature can be quantified as, **Q 10** which is the relative increase for a **10°C** rise in temperature..
- Enzyme activity is not zero at **0°C** so still work in refrigerator, but they work slowly.
- Enzymes can even work in ice.
- In ice, enzymes work is extremely slow due to very slow diffusion of enzyme and substrate though the ice lattice.

**BTB**

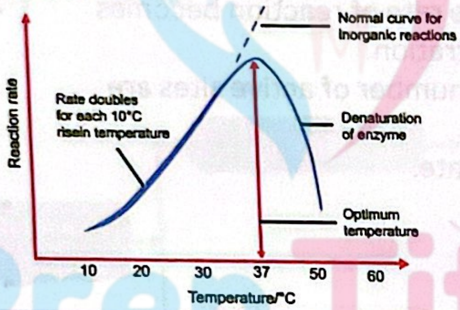
- Some enzymes work maximum in acidic medium like pepsin etc.
- Others work maximum in neutral medium like amylase etc.
- Remaining work maximum in alkaline medium like lipase etc.
- A restriction enzyme is an enzyme that

## TEMPERATURE

- By increasing temperature, molecular motions and vibrations of particles increase.
- Probability of reaction increases because heat supplies kinetic energy and increases collision frequency between particles.
- Temperature of maximum activity is optimum temperature
- For enzymes of human body **37°C** is the optimum temperature
- Above optimum temperature, enzyme's secondary and tertiary structure disrupts, and enzyme **denatures**.
- The temperature which causes denaturation is called **maximum temperature.**

### PTB

- Heat provides activation energy and therefore, chemical reactions are accelerated at high temperatures.
- If the vibrations become too violent due to large increase in Heat energy, globular structure essential for enzyme activity is lost and the enzyme is said to be denatured.




- cleaves DNA in fragments.
- These enzymes found in bacte and provides a defence mechanism aga invading viruses
- They restrict the entry of foreign DNA in the host
- In non-living system, heat provides activa energy.
- For living system heat is not provided rather than enzymes lo the activation energy.
- Heat cannot be used here becau it can denature proteins and enzymes.

### TIT BIT

- Penicillin blocks the active site an enzyme uni to bacteria.
- When it is take bacteria die b humans are unaffected.

## pH

- All the enzymes work maximum at very narrow range of their sensitive pH called **optimum pH.**
- Change in the pH results in disruption of charge of amino acids chain that are involved in secondary and tertiary conformation
- Slight change in pH results in change in ionization of amino acid & It may also effect the ionization of substrate.
- The enzyme becomes inactive temporarily or blocked completely.
- Extreme change in pH affects ionic change of acidic and basic groups of enzymes and disrupt the structure permanently causing denaturation.
- It causes the bonds in enzymes to break.

### PTB

| Enzyme | Optimum pH | Site of Action | Function |
|---|---|---|---|
| Pepsin | 2 | Lumen of the stomach | Hydrolysis of proteins |
| Sucrase | 4.50 | Small intestine | Hydrolysis of sucrose |
| Enterokinase | 5.50 | Small intestine | Activation of trypsinogen |

| | | | |
|---|---|---|---|
| Salivary amylase | 6.80 | Oral cavity | Digestion of carbohydrate |
| Chymotrypsin | 7 – 8 | Predominantly in liver | Decomposition of $H_2O_2$ |
| Catalase | 7.60 | Small intestine | Involved in proteolysis |
| Pancreatic lipase | 9 | Small intestine | Hydrolysis of fats |
| Arginase | 9.70 | Liver | Catalysis of arginine into urea |

## FTB

- Every change in **10°C** can double the reaction.
- Bonds that are sensitive to temperature are hydrogen bonds.
- Human enzymes have optimum temperature of **37-38°C.**
- Enzymes of Bacteria living in hot spring have optimum temperature of **70°C.**
- Such enzymes are used in biological washing powders and detergents. That's why cloth washing need lukewarm water, not to hot.
- Temperature at which in-active enzymes become active again is called **minimum temperature.**
- Most of the enzymes work at **pH 6 – 8.**
- Papain enzyme works both in acidic and basic medium.
- Trypsin work at pH = **8 (alkaline)**

| Enzyme | pH (optimum) |
|---|---|
| Lipase (Pancreas) | 8.0 |
| Lipase (Stomach) | 4-5 |
| Lipase (Castor oil) | 4.7 |
| Urease | 7.0 |
| Inverses | 4.5 |
| Amylase (Pancreas) | 6.7 – 7.0 |
| Amylase malt | 4.6 – 5.2 |

## BTB

- Enzymes which catalyse reaction again and again are called **regulating enzymes.**
- Irreversible inhibitors often contain reactive functional group like aldehydes etc.
- These electrophilic groups make covalent bonds with amino acid chains.
- Reversible inhibition is done by non-covalent interactions like H-bond, hydrophobic interaction, or ionic bond etc.

## KPK

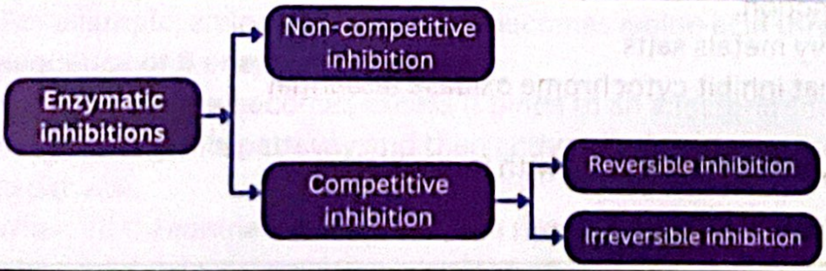
- **Sulphonamide** to an antibacterial drug which acts as competitive inhibitor.

# ENZYME INHIBITION

- Phenomenon in which enzymes fail to catalyse the reaction due to
- enzyme inhibitors.
- An inhibitor is a chemical substance which can react (in place of substrate) with the enzyme but is not transformed into product(s) and thus blocks the active site temporarily or permanently.
- It is normal part of regulation of enzymes activity in cells.
- But when sometimes external factors cause enzyme inhibition, it becomes dangerous for life.
- Such inhibitors are poisons, cyanide, antibodies, antimetabolites, penicillin, sulpha drugs etc.

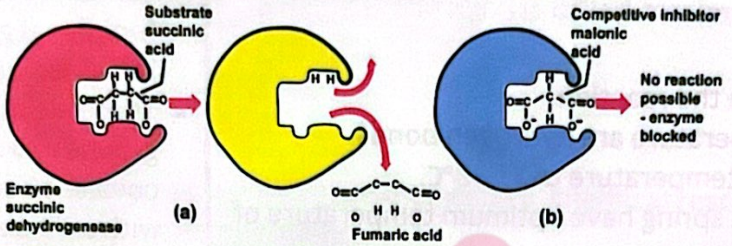


## TYPES



## COMPETITIVE INHIBITION

- Inhibition in which enzyme action is blocked by presence of chemical which is resembled to substrate for binding site on active site.
- It is chemically not similar but structurally similar.
- It is also known as reversible inhibition because it is **temporary.**
- If the concentration of substrate is increased, the inhibition will be diminished.
- For example, succinate dehydrogenase that catalyses the formation of fumarate from succinate is inhibited by malonate.




### FTB

- **Importance of Competitive Inhibitors:**
- It supports **lock and key model.**
- It shows that substances which are similar to substrate are not acted upon by enzymes.
- They are used as **drugs** to control bacterial pathogens.
- Antibiotics e.g., sulphonamides are used to combat bacterial Injection.

## NON-COMPETITIVE

- Inhibition in which inhibitor molecule binds enzyme site other than active site.
- The other site is **allosteric site.**
- Non-competitive inhibition can be:
- Reversible (Inactivates the enzyme temporarily).
- Irreversible (Denatures the enzyme permanently).

## REVERSIBLE (TEMPORARY)

- This inhibition works by Preventing formation of enzyme-product complex
- They prevent to convert substrate into product.
- Example is feedback inhibition (final product inhibition) is reversible non-competitive.

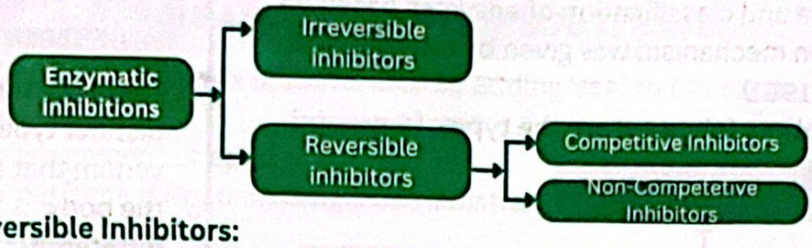
## IRREVERSIBLE

- In this inhibition, inhibitor destroys the shape of enzyme even if real substrate combines, fails to function.
- For example, cyanides and heavy metals salts.
- Cyanides are potent poisons that inhibit cytochrome oxidase (essential for cellular respiration).
- They block action of these enzymes by combining with iron which may be present in prosthetic group.

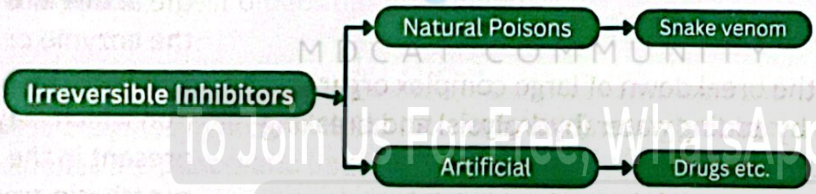
**FTB**

- Ions of heavy metals combine with – **SH group** (thiol) in enzymes breaking the disulphide bridges.
- These bridges are important in maintaining the tertiary structure. When these bridges are broken enzymes become denatured and inactive.

**PTB**



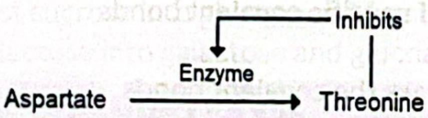

- **Irreversible Inhibitors:**
- They check the reaction rate by occupying the active sites or destroying the globular structure.
- They occupy the active sites by forming covalent bonds or they may physically block the active sites.
- **Reversible Inhibitors:**
- They form weak linkages with the enzyme.
- Their effect can be neutralized completely or partly by an increase in the concentration of the substrate.
- **Competitive Inhibitors:**
- Have structural similarity with the substrate & is selected by binding site but can't activate the catalytic site.
- No product formation occurs.
- Non-competitive inhibitors alter the structure of the enzyme in such a way that even if genuine substrate binds the active site, catalysis fails to take place.






## FEEDBACK INHIBITION

- Process of inhibition of enzyme by its own product.
- Type of **reversible, non-competitive inhibition.**
- It is a normal **regulatory mechanism** and happens during the regulation of metabolic pathways.




- **For example,** amino acid aspartate becomes amino acid threonine by a sequence of **5 enzymatic reactions.**
- When threonine becomes excess it binds to an allosteric site on enzyme 1 on this pathway and then active site is no longer to bind aspartate.
- When all threonine is consumed, the process become normal

**EXTRA INFORMATION**

**DIAGNOSTIC USES OF ENZYMES**

- **(a) Aldolase:** Progressive muscular dystrophy, viral hepatitis, and advanced cancer of the prostate.
- **(b) Creatine Phosphokinase:** Damage to muscle cells.
- **(c) Gamma-glutamyl Transpeptidase:** In assessing liver function.
- **(d) Lactic Dehydrogenase:** In differentiating heart attack, anemia, lung injury, or liver disease.
- **(e) Lipase:** Damage to the pancreas.

**VENOMS AS ENZYME INHIBITORS**

- **Snake venom** is highly modified saliva that is produced by special glands of certain species of snakes.
- Snake venom is a combination of many toxins (proteins) and different enzymes, used for purposes like increasing the prey's uptake of toxins.
- Snake venom inhibits cholinesterase to

FTB

## CLASSIFICATION OF ENZYMES

- Enzymes can be classified either on the basis of reaction types that they catalyze or on the basis of substrate which are acted upon by the enzyme.

### ON THE BASIS OF REACTION TYPE

- A systematic nomenclature and classification of enzymes based on reaction types and reaction mechanism was given by International Union of Biochemistry (**In 1961**).
- According to this classification, following are the types: (**6 groups**)

Enzymes
- Oxido-reductases
- Transferases
- Hydrolases
- Lyases
- Isomerases
- Ligases

### OXIDOREDUCTASES

- These enzymes catalyze oxidation/reduction of their substrate and act by removing or adding electron or **$H^+$ ions** from or to the substrate.
- For example, **cytochrome oxidase** oxidizes cytochrome.

### TRANSFERASES

- These enzymes catalyze the transfer of specific functional group other than hydrogen from one substrate to another.
- The chemical group transferred in the process is not in a free state, for example hexokinase transfers a phosphate group from ATP to glucose.



### HYDROLASES

- These enzymes bring about the breakdown of large complex organic molecules into smaller ones by adding water (hydrolysis) and breaking the specific covalent bonds.
- Examples are proteolytic enzymes which breakdown proteins into peptides and amino acids such as **pepsin, renin, and trypsin.**
- Other digestive enzymes that work in digestive tract are also the examples of hydrolases.

### LYASES

- These enzymes catalyze the breakdown of specific covalent bonds and removal of groups without hydrolysis.
- For example, **histidine decarboxylase** breaks the covalent bonds between carbon atoms in histidine forming carbon dioxide and histamine.

### ISOMERASES

- These enzymes bring about intra-molecular rearrangement of atoms in the molecules and thus forming one isomer of another.

to make the prey lose control of its muscles.
- Venom is an inhibitor for an essential enzyme cytochrome oxidase in the cell.

### VENOM THAT ACTS ON THE BODY DIFFERENTLY

- There are three distinct types of venom that act on the body differently
- **Hemotoxic venoms:** Act on the heart and cardiovascular system.
- **Neurotoxic venoms:** Act on the nervous system and brain.
- **Cytotoxic venoms:** Have a localized action at the site of the bite.
- Venom occupies the active site of the enzyme or combines with the iron which may be present in the prosthetic group, which may be required as an enzyme activator.

- For example, **phosphohexose isomerase** changes glucose 6-phosphate into fructose 6-phosphate.

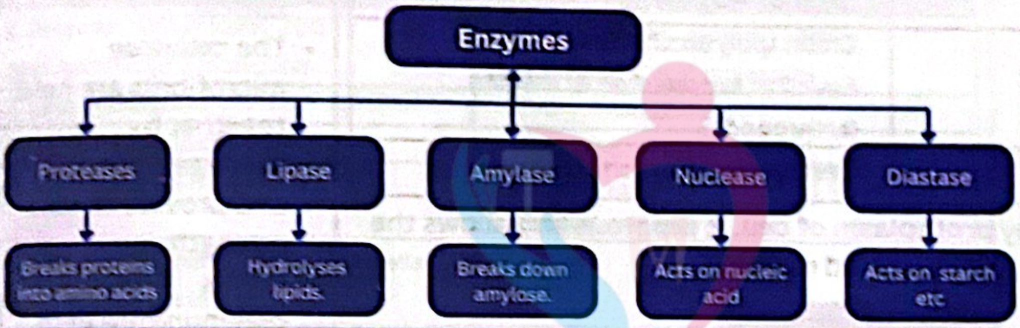
## LIGASES (SYNTHASES)

- These enzymes bring about joining together of two molecules. The
- energy is derived by hydrolysis of ATP.

For example, **polymerases** are responsible for linking monomers into a polymer such as DNA or RNA.

## ON THE BASIS OF NAME OF SUBSTRATE

- The name of enzyme is often formed by adding 'ase' to the same substrate.
- They are named for action.
- They performed like dehydrogenase substrate i.e., remove H+ from substrate. **Examples:**




## PROTEASES

- These enzymes act upon proteins.
- Examples are **pepsin and trypsin** (both digest large polypeptides into small polypeptides or peptones), **aminopeptidases and carboxypeptidases** (both act upon small peptides to amino acids), and **erypsin** (digest dipeptides into amino acids).

## LIPASES

- These enzymes hydrolyze lipids into fatty acids and glycerols.
- Examples are **pancreatic lipases.**

## CARBOHYDRASES

- These enzymes cause breakdown of carbohydrates. Examples are:
- a) **amylase** (digest starch into maltose)
- b) **maltase** (digest maltose into glucose)
- c) **cellulase** (digest cellulose into cellobiose and glucose)
- d) **invertase** (digest sucrose into glucose and fructose)
- e) **lactase** (digest lactose into galactose and glucose)

## NUCLEASES

- These are involved in the breakdown of DNA and RNA. Examples are:
- a) **RNases** (digest RNA into ribonucleotides)
- b) **DNases** (digest DNA into deoxyribonucleotides)
- c) **ATPases** (cause hydrolysis of ATP in muscles, etc.)

# CELL STRUCTURE & FUNCTION

## Cell Wall

- The **outermost boundary** in most of plant cells, prokaryotes, fungi & also in algal cells.
- Cell wall is **absent in animal cells** due to their locomotor mode of life.
- Call walls of prokaryotes and plants differ due to their chemical composition and structure.

| # | ORGANISM | CHEMICAL COMPOSITION |
|---|---|---|
| 1 | Prokaryotes | Peptidoglycan or murein<br>As a whole sacculus<br>(peptide fragments + carbohydrates) |
| 2 | Fungi | Chitin (polysaccharide)<br>Found in exoskeleton of insects (arthropods) |
| 3 | Plants | Cellulose (polysaccharide) |

- Cell wall is secreted by **protoplasm of cell**. It is porous and allows the free passage of water and dissolved material.

Layers of cell wall

1. Middle lamella
2. Primary wall
3. Secondary wall



### MIDDLE LAMELLA

- Middle lamella is present between adjacent primary walls of two cells & is thin.

### PRIMARY WALL

- Primary wall is a **true wall** and develops only in a newly growing cell during cell division.
- Each cell produces a primary cell wall.
- It is **composed** of cellulose, pectin and hemi-cellulose.
- Cellulose fibrils are arranged in a criss cross manner (**right angle to each other**)

### SECONDARY WALL

- Secondary wall is formed between primary wall and plasma membrane (on inner surface of primary wall)
- It is rigid and thick.
- It is composed of inorganic salts (**$Ca^{+2}$, $Mg^{+2}$, $K^{+}$** etc) silica, waxes, cutin and lignin.

### FUNCTIONS

**BTB**

- It is a non-living structure.
- The outer part of primary wall of plant is impregnated with cutin and waxes, forming a permeability barrier known as **plant cuticle.**
- The cellulose microfibrils are held together by hydrogen bonding and provide tensile strength.
- Plants communicate with each other through microscopic channels known as **plasmodesmata.**
- Some plant cells possess only primary cell wall such as leaves, storage cells & the young growing cells.

**KPK**

- Cell wall was Discovered by Robert Hook in **1665** earlier than protoplast.

- Cell wall provides definite shape to cell & keep it rigid.
- Cell wall contains pores through which substances pass through freely and is called as **freely permeable membrane.** (Don't act as barrier to the materials passing through it.)
- Cell wall maintains cell shape provides protection and mechanical support.

**PTB**

- Middle lamella is the first layer to be formed between the primary walls of neighbouring cells.

**FTB**

| PECTIN | PECTIC ACID |
|---|---|
| 1. Polymer of around 200 galacturonic acid molecules | 1. Polymer of around 100 galacturonic acid molecules |
| 2. Less hydrophilic | 2. Very hydrophilic |
| 3. More methylated | 3. Less methylated |
| 4. Soluble in hot H2O | 4. Forms salts with Ca++ and Mg++ that are insoluble gel. |
| 5. Major component of middle lamella but also present in primary walls. | |

- The primary cell wall is present inner to middle lamella.
- Primary wall is thin and flexible.
- Primary wall stretches plastically i.e., irreversibly.
- Secondary wall is dead and is found only in sclerenchyma cells & provide support.
- Secondary wall develops only when cell reached its maximum size. (growth is complete). Its cellulose microfibrils show criss-cross arrangement.
- Lignin in secondary wall is responsible for rigidness and anchors cellulose microfibrils.
- Middle lamella is composed of sticky gel-like calcium and magnesium salts and pectin.
- Middle lamella is cementing material or substance.
- Both primary and secondary walls are crystalline and optically active.
- Cell wall prevents over- expansion.

## CELL MEMBRANE

- Cell membrane or plasma membrane is the **outermost boundary** of **protoplasm** in animal cell.
- It lies beneath cell wall in plants, algal, fungal and bacterial cell.
- The structure of membrane remains intact due to **hydrophobic interactions.**
- It is chemically called **lipoprotein.**
- Proteins within the membrane determine most of the functions.
- Plasma membrane is asymmetrical i.e. two halves and surfaces are not identical.

### USES OF CELLULOSE IN INDUSTRY

- **Nitrocellulose:** Used as explosives.
- **Rayon:** Used in textile fibers.
- **Cellophane:** Partially permeable membrane.
- **Paper making:**
- **Celluloids and cinematography:** As plastic.

### THICKNESS OF PRIMARY WALL, SECONDARY WALL AND MIDDLELAMELLA

- **Middle lamella:** 1 μm
- **Primary cell wall:** 1 – 3 μm
- **Secondary wall:** 5 – 10 μm

In woody tissues the middle lamella is commonly lignified.

**BTB**

- Plasma membrane is living boundary.
- Phospholipid is most abundant lipid in plasma membrane and give basic structure.
- There are **two kinds of membrane protein.**
- **Intrinsic (integral) or embedded Protein**

## FLUID MOSAIC MODEL (MOST ACCEPTABLE MODEL)

- According to this model, cell membrane is composed of a lipid bilayer.
- Proteins are not continuous and not confined to cell surface. Membrane proteins are embedded in lipid bilayer in a mosaic manner
- like ice barges float in sea randomly. Proteins are embedded wholly or partially.

**Chemical composition of cell membrane**

- Proteins 60 – 80% (Mosaic manner)
- Lipids 20 – 40% (Fluidity)
- Carbohydrates (small amount)

## FUNCTIONS OF CELL MEMBRANE

- One of the most important functions of cell- membrane is to control **transport of material** across it. It gives **shape & mechanical support** to cell.
- Cell membrane allows only selective substances to pass through it; therefore, it is known as **selectively or differentially permeable membrane.**
- Non-polar or neutral substances can easily across the membrane e.g. gas molecule, water, glucose etc.
- It gives shape & mechanical support to cell.
- Filaments of cytoskeleton are also present on the inner surface and support plasma membrane.
- In nerve cell (neuron), the cell membrane transmits nerve impulses from one part of body to other to keep co-ordination.



**PTB**

## UNIT MEMBRANE MODEL

- According to this model, lipid bilayer is sandwiched in between inner and outer layers of proteins.
- This basic earlier model is present in all cellular organelles.
- Modern technology rejected this model.

## FUNCTIONS

- Cell membrane also contains charge pores through which movement of material takes place both by active and passive transport.
- It regulates the flow of material and ions to maintain definite gradient.
- Small molecules (water, glucose) can easily cross the membrane.
- Lipid soluble substances cross it more easily.
- Ions being charged particle have difficulty in crossing.
- Many substances which are not needed constantly enters the cell by passive transport while others are taken up by active transport
- Cell membrane helps to take material by enfolding in the form of vacuoles. This intake is called **endocytosis**.

(e.g. permeases regulate diffusi osmosis and ac transport of ion materials.)

**Extrinsic or surface protein** (e.g., receptors)

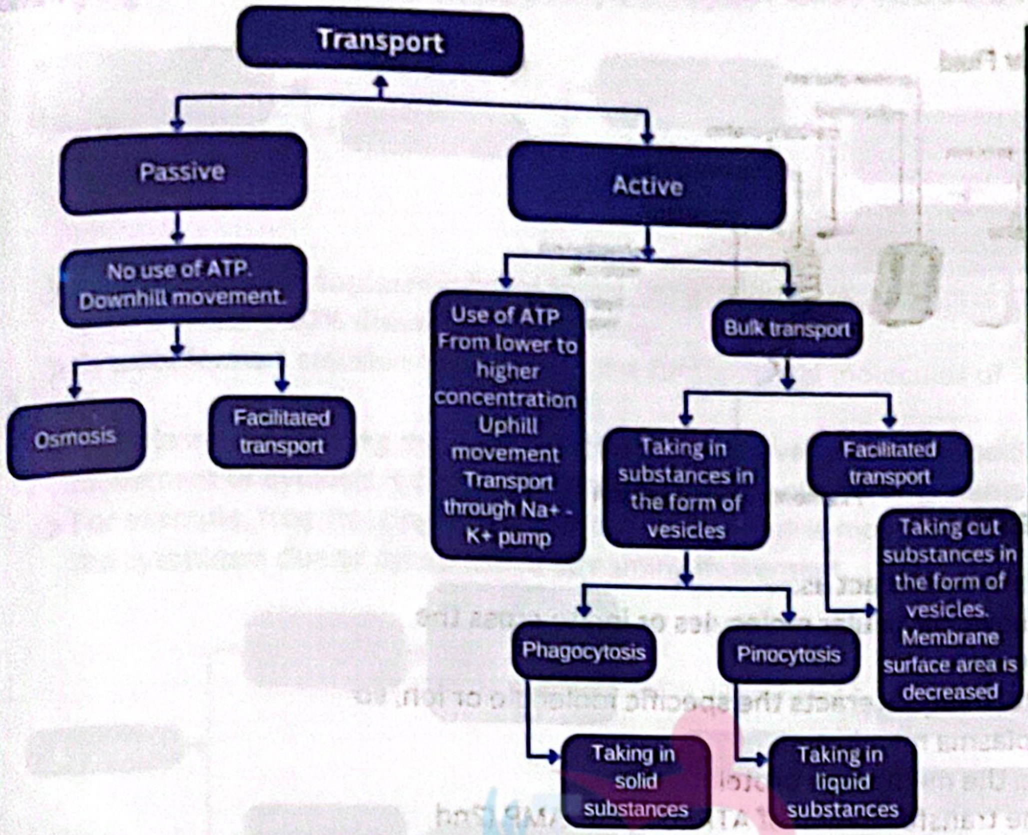
**KPK**

**CHRONOLOGICAL DEVELOPMENTS TOWARDS FLUID MOSAIC MODEL OF PLASMA MEMBRA**

- **Gorter & Grendel 1925:** Two layers of lipid molecules o
- **JF Danielle & Davison 1935:** Lipi bilayer is covered with proteins & protein pores
- **Robertson 1959:** Unit membrane model
- **SJ Singer & GL Nicholson 1972:** Fluid mosaic mod

**KPK**

- Lipids, proteins and carbohydrat are responsible f functional diversity of the membranes.
- Lipid bilayer makes the membrane differentially permeable barr
- It allows the transport of no polar materials across it and prevents ionic materials.




- Membrane proteins on the other hand makes it selectively permeable barrier that select materials according to cell's need.
- If glucose concentration inside the cell is proper, no more glucose can enter the cell.
- Plasma membrane is dynamic structure.
- Membrane carbohydrate responsible for pinocytosis phagocytosis are (cell surface marker)

## FTB

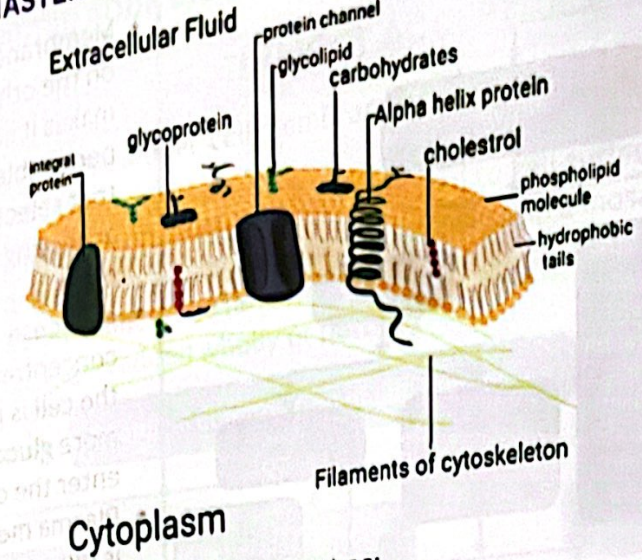
- Carbohydrates are in the form of conjugated glycolipids, glycoproteins in cell membrane (generally on outer surface).
- Glycoproteins and glycolipids are cell surface markers (like signboard on a shop) which help in cell-to-cell recognisation, stick and connect two cells together in tissues.
- Cell membrane is found in all living prokaryotes and eukaryotes.
- The pattern of distribution of protein can vary from membrane to membrane and also vary both surfaces of membrane.
- The membrane is about **7nm thick (wide)**
- Hydrophobic ends of phospholipids are inward and face to each other.
- Hydrophilic ends are appeared on the surface.
- **The Steroids, Cholesterol** are embedded in phospholipid bilayer at some intervals.
- Cholesterol molecules help to stabilize the phospholipid bilayer at body temperature, but it helps to keep the membrane fluid at low temperature.

  It also restricts entry of polar molecules and ions.

  Fluidity of membrane is due to **lipid component** of membrane including **3 classes of amphipathic lipids:**

(i) Phospholipid (ii) Glycolipid (iii) Cholesterol

- When the concentration of unsaturated fatty acid in phospholipid becomes greater, the bilayer becomes more fluid that makes cell-membrane more flexible.




- Proteins of cell membrane may act as:
- **Channel protein:** It allows particular molecules or ion to cross the plasma membrane freely
- **Carrier protein:** It selectively interacts the specific molecule or ion, so that it can cross the plasma membrane.
- **Enzyme:** For example, the membrane protein
- **Cyclase:** Catalyses the transformation of ATP to cyclic AMP (2nd messenger)
- **Receptor:** Receives signals from other cells. Binding of molecule to specific receptor brings about intracellular response.
- **For example,** hormone circulates in blood but bind to specific target cell called receptor.
- **Antigen:** Foreign antigen can be recognized and attacked by immune system. Use in body defence system.

**Transport across membrane occurs to**

- Obtain nutrient
- Excrete waste substances
- Secrete useful substances
- Maintain suitable pH and ionic concentration for enzymatic activity
- Generate ionic gradient essential for nervous and muscular activity



## CYTOPLASM

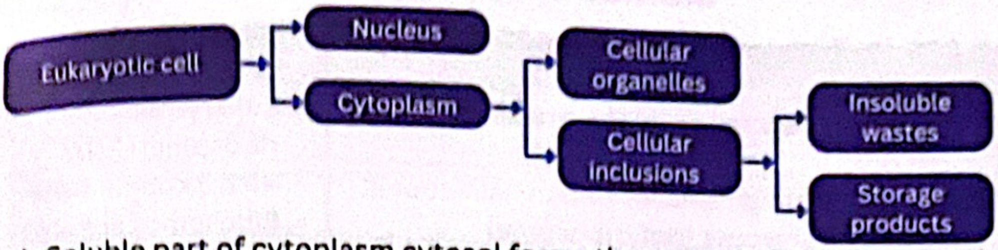
- The living contents of the eukaryotic cell are divided into nucleus and cytoplasm, the two collectively called **protoplasm**.
- Cytoplasm is the region between nuclear membrane and plasma membrane.

### FUNCTIONS

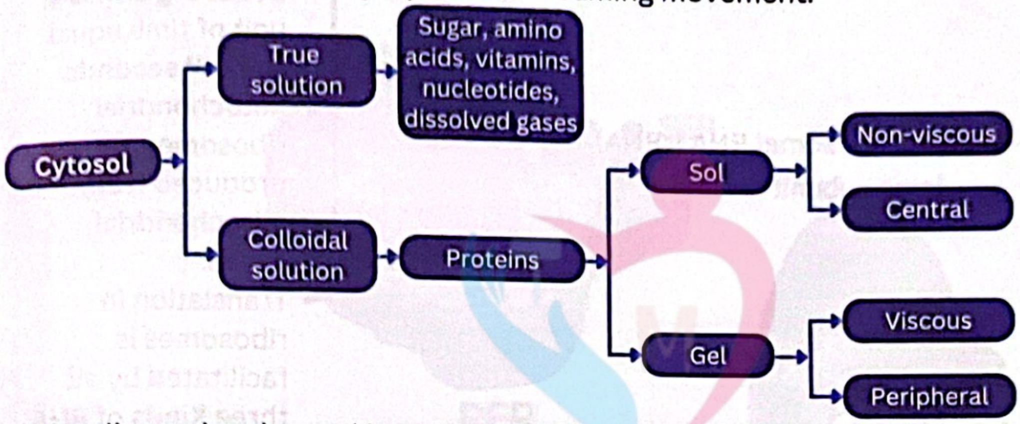
- **Store house of vital chemicals:**
- Useful substances used in various cellular activities. e.g. glycogen
- Waste compounds are removed out of the cell time to time.
- **Metabolic activities:**
- Many important metabolic reactions take place in cytoplasm e.g., Protein synthesis, glycolysis, glycogenolysis, gluconeogenesis etc.

**BTB**

- The word cytoplasm literal means **living gel** of **cell.**
- Cytoplasm conta both **organic** and **inorganic substances.**
- Cytoplasm of eukaryotes maintains shape cell by organelle cytoskeleton present inside it.
- **Colloidal solutio** the type of soluti which contains t suspended partic in it.
- **e.g. starch partic** in plant cell & glycogen granule animal cells.




- Soluble part of cytoplasm cytosol forms the ground of cytoplasm and is **90% water & 10% dissolved substances.**
- Cytosol forms a solution that have all the fundamental molecules of life.
- Cytoplasmic streaming movement, active mass movement, amoeboid movement or cyclosis is due to **contractile activity of microfilaments**
- For example, free-floating organelles like mitochondria move about in the cytoplasm due to cytoplasmic streaming movement.




- Smaller molecules and ions form the true solution while larger molecules form the colloidal solution.

**FTB**

- Cytoplasm is the **common component** of both prokaryotes and eukaryotes.
- The major difference between cytoplasm of these two types of cells is presence of **cytoskeleton** or absence of **cytoskeleton** and membrane bound organelles.
- These structures are absent in prokaryotic cells.
- Metabolic reactions take place in cytosol.
- Storage of compounds take place in **cytogel part** of cytoplasm.
- Cyclosis is responsible for distribution of cell contents in cytoplasm.



## RIBOSOME

- Tiny granular structures in the cell called ribosomes.
- Ribosomes were first studied by **Palade in 1955.**
- Ribosomes are made up of equal amount of RNA and Protein known as **ribonucleoprotein.**
- Ribosomes in exist in two forms:
  - Attached to RER as tiny granules. - Freely dispersed in cytoplasm.
- Ribosome consists of two ribosomal subunits called **Svedberg units**
- Svedberg is used in ultra-centrifugation technique.
- One is larger other is smaller subunit.
- **Prokaryotes ribosome** is **70S**, in which larger subunit is **50S** and smaller is **30S**.

**BTB**

- Engine of cell or factory for protein synthesis.
- Ribosomes are absent in mammalian RBCs.
- Smallest organelle also called organelle within an organelle.
- **Prokaryotic**

- **Eukaryote's ribosome** is **80S**, in which larger subunit is **60S** and smaller is **40S**.
- The attachment of both subunits is controlled by the presence of **$Mg^{+2}$ Ions:**
- Ribosomes are attached to mRNA through smaller ribosomal Subunit. **Single mRNA + Many ribosomes = Polysome (polyribosome)**
- Ribosomes are involved in protein synthesis (polypeptide) this process called translation starts from **5'end** of mRNA and ends at **3'end.**
- Ribosomes are synthesized from nucleolus (factory of ribosome). An example is of protein synthesized by free ribosomes in Hb in young RBCs.
- Ribosomes are then transported outside in cytoplasm through nuclear pores.

**PTB**

- Ribosome contains RNA called ribosomal RNA (rRNA).


**FTB**

- Ribosome is dense, roughly spherical, granular and non-membranous organelle.
- Common organelle present both in eukaryotic prokaryotic cells
- Diameter of ribosome is **20 – 24 nm.**
- Ribosomes are also found in **matrix** of mitochondria and **stroma** of chloroplast, but these ribosomes are of prokaryotic nature (70S).
- Attachment of ribosomal subunits is also controlled by forming salt bonds between phosphate group of RNA and amino group of amino acid and by means of **$Mg^{++}$ ions.**
- In polysome, several copies of same polypeptide chain are produced in very less time.

## ENDOPLASMIC RETICULUM (ER)

- Under an electron microscope, ER is interconnected channel of cisternae channel that extended from nuclear membrane to plasma membrane.
- Materials in these channels separated fem cytoplasmic content through cisternae membranes (spherical or tubular membranes).
- **Two forms of ER:**

**ribosome: rRNA 60%, protein 40%**
- **Eukaryotic ribosome: rRNA 40%, protein: 60%**
- Ribosomes are also attached to outer surface of nuclear membrane.
- **About half a million** ribosomes are found in eukaryotic cells.
- Svedberg unit is a unit of time equal to $10^{-13}$ **seconds.**
- Mitochondrial ribosomes are produced from mitochondrial genes.
- Translation in ribosomes is facilitated by all three Kinds of RNA and under the instructions of DNA

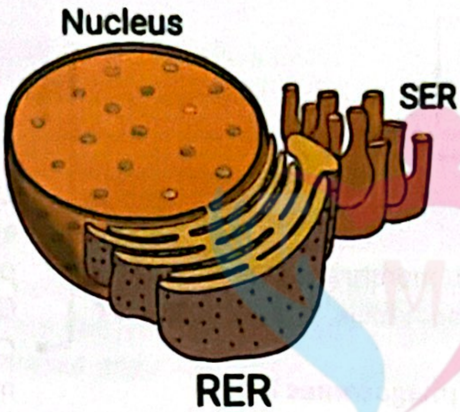
**KPK**

- Due to small size **(20nm diameter)**, ribosomes are the last organelle to be sedimented requiring a force of **150,000 times** gravity for **3 hour**

**EXTRA POINT**

- **Attached ribosomes:** Synthesize protein that is transported outside the cell.
- **Free ribosomes:** Synthesize protein that is utilized.

| SER | RER |
|---|---|
| 1. Ribosomes are not attached on outer surface. | 1. Ribosomes are attached on outer surface. |
| 2. Also known sarcoplasmic reticulum in muscle cells. | 2. Involved in protein synthesis, storage and transport. |
| 3. Less stable structure. | 3. More stable structure. |
| 4. Mainly composed of tubules. | 4. Mainly composed of cisternae and vesicles. |
| 5. Abundantly occurs in cells, concerned with glycogen and lipid metabolism such as adipose tissue, muscles, liver cells and also remove toxins. | 5. Abundantly occurs in cells which are actively engaged in protein synthesis and secretion such as in liver, pancreas and goblet cells. |




- **SER is involved in:**
- Detoxification of drugs & poison.
- Elimination of harmful chemicals and substances.
- Metabolism of carbohydrates and lipids. Cholesterol and phospholipid metabolism is done by **SER**
- Transmission of impulse (in nerve and muscle cells).
- Along with microfilaments and microtubules, both **SER** and **RER** provides mechanical support to cell.

**PTB**

- SER is also involved in **Ca⁺⁺** storage and transport of material from one part of cell to other.

**FTB**

- **RER** has ribosomes attached to sides facing the cytoplasm.
- Most cells contain both types of **ER**. However, some cells have more **SER** (such as muscle cells).
- Products formed are on **RER** are passed through **SER** thus involved in transport of various cellular products into or out of cells.

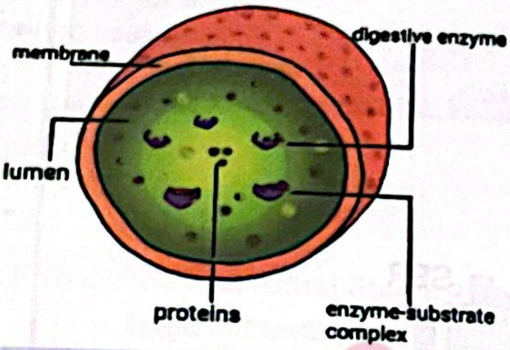
## LYSOSOME

- Lyso means **"splitting"** and soma means **"body"**.
- Lysosome is single membranous, spherical (vesicles) cytoplasmic organelle found in most eukaryotic cells.
- They are simple sacs rich in **acid phosphatase & hydrolytic enzymes.**

**BTB**

- ER divides the intracellular space into two distinct compartments i.e. luminal (inside) and extra luminal (cytoplasm).
- **Cisternae:** These are long flattened and unbranched units arranged in stacks.
- **Vesicles:** These are oval membrane bounded structures.
- **Tubules:** These are irregular often branched tubes bounded by membrane.
- They may be free or connected with cisternae.
- If many ribosomes are attached on the small parallel cisternae of RER then it is called **ergastoplasm**
- In nerve cell, ergastoplasm are known as **Nissl's body.**
- **Cellular metabolism:** The membrane of ER increases surface area for metabolic activities, also contains some enzymes like sucrase, glucose-6-phosphatase, NAD-Bl-phosphatase etc.
- **Formation of nuclear membrane:** Fragmented

- These enzymes are synthesized by ribosomes on RER and are further processed in Golgi apparatus.
- After modification, these enzymes are released in the form of Golgi vesicles (from trans face of Golgi complex) and are known as **primary lysosomes.**
- Vesicles before performing their functions are called **primary lysosomes.**
- Lysosomal enzymes work in **acidic medium.** These enzymes can digest the phagocytosed food particles.




## FUNCTIONS

- To perform its function lysosome fuses with membrane bound vesicle that arises from any of these pathway's endocytosis, phagocytosis, or auto phagocytosis.
- These vesicles are referred as **endosomes, phagosomes & auto phagosomes.**

**Major functions of lysosomes are:**

1. **Intracellular Digestion:** The ingested food of stored in vesicles cell is called food vacuole. Food vacuole combines with lysosome and called **secondary lysosome.**
   - The digested food is absorbed in cytoplasm. Remaining wastes containing vesicles are called **contractile vacuoles.**
2. **Exocytosis:** Then these contractile vacuoles are excreted out through exocytosis.
3. **Autophagy:** Unwanted worn-out structures within the cell are engulfed by the cell itself is called **autophagy** and these lysosomes are known as autophagosomes (secondary lysosome)
   - It is self-eaten process (cell materials are recycled or renewed).
   - During exercise, larger number of mitochondria are produced to obtain energy. These mitochondria are again decreased by autophagy after exercise.
4. **Autolysis:** *During developmental processes, when a cell is required to be disintegrated, a type of cell death occurs called* **"autolysis".** *(programmed cell death).*
   - *This is done by the enzymes of lysosomes released due to its bursting.*

## STORAGE DISEASES (DUE TO FAULTY LYSOSOME)

- Several congenital diseases have been found to be due to accumulation within the cell of substances such as glycogen or various glycolipids. These are also called **storage diseases.**

elements of disintegrated nuclear membrane and ER arranged around chromosome to form nuclear membrane during cell division.

- All membranous organelles except chloroplast and mitochondria are formed by ER.

**KPK**

- SER makes lipids from fatty acids an glycerol and absorbed in gut an passes them to Golgi apparatus.
- Corticosteroids made in adrenal cortex, testosterone, estrogenic initiated in SER.

**BTB**

- Lysosomes break macromolecules in cell.
- They are **absent in mammalian RBCs.**
- Lysosomes are les in number in plant
- **Fungi** also contain many Lysosomes.
- **Periplasmic space in bacteria** may function as lysosome.
- Lysosomes also contain **hydrolyt enzymes** like carbohydrase's, lipases, nuclease and proteases
- Lysosomes vary

- They produced by a **mutation** that effect one of the **lysosomal enzymes** involved in the catabolism of a certain substance.
- There are about **20 such diseases.**
- These can be hereditary and congenital.
- Most of these are fatal in early childhood.
- **Glycogenesis type II disease:** This disease is due to accumulation of glycogen in cell because enzyme involved in the breakdown of glycogen to glucose absent.
- **Tay Sach's disease:** This disease is due to accumulation of lipids in brain- because enzyme involved in catabolism of lipid of absent.
- This disease causes mental retardation, blindness, paralysis and even can be fatal.

**PTB**

- Any foreign object that enters cell is broken into simple digestible pieces by lysosomes (phagocytosis).
- Digested vacuoles and auto- phagosomes are secondary lysosome
- Lysosomes were isolated for the first time by **De-Duve in 1949.**
- Lysosomes are most abundant in those animal cells which exhibit phagocytic activity e.g., neutrophils etc.
- Autophagy either takes place in starvation to provide energy or occurs in routine to regulate the number of certain organelles. Lysosomes also release enzymes for **extra cellular digestion.**

**FTB**

- Lysosomes contain about **40 different digestive enzymes.**
- In plants and fungi, certain vacuoles may act as lysosome (carry out enzymatic hydrolysis).
- Lysosome is also called **suicidal bag (because of autolysis).**

## GOLGI APPARATUS

- Found in all eukaryotic call.
- Found by **Camilo Golgi (Italian biologist) in 1898.**


- Consists of stack of flattened membrane bounded sacs called **cisternae** arranged in concentric way.
- **Cisternae + associated vesicles = Golgi Complex**
- Formed by the fusion of vesicles, breaking up from **SER.**
- **Outer surface** is convex, cis, proximal, forming face.
- **Inner face** is concave, trans, distal, maturing face.
- Cisternae break into vesicles at maturing face.

size from 0.1 - 0.8 µm in diameter.

- In phagocytic WBC, it is largest in size (0.8 – 2 µm).
- They are also known as **polymorphic cellular organelle** because they exist in different morphological and physiological States during their function.
  **Primary lysosome + Food vacuole = Digestive vacuole or phagosome**
- Lysosome containing undigested matter is called **residual or tertiary lysosome.**
- In unicellular organisms, they are removed outside by exocytosis.
- In multicellular, they are retained in the cell in the form of **lipofuscin granules.**
- Autophagosomes are also called **cytolysosomes.**
- Human liver cells recycle half of its macromolecules each week.
- It digests foreign substances received through endocytosis.
- This is called **heterophagy.**
- **Extracellular digestion:** Lysosome of osteoclast ;(bone eating cells) dissolve unwanted

# GOLGI APPARATUS

- Main function is **cell secretion,** found abundantly in secretary cells.
- Products (secretions) are passed from:

Ribosomes → RER → SER → Golgi → Vesicles → Lysosome → Exocytosis

- **Modification (glycosylation) of carbohydrates into glycoprotein and glycolipid** also its main function.

## PTB

- It is the **complex system of interconnected tubules** around central stacks.
- The whole stack consists of a number of cisternae thought to be moving from outer to the inner face.
- Finishing and packing of products is the function of Golgi.
- In mammals, pancreases secrete granules having digestive enzymes. Golgi complex has a role in the formation of these granules.
- These granules are transported out of cell through Golgi.

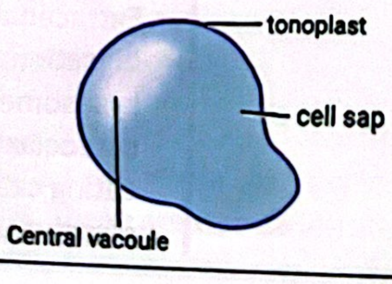
## FTB

- Lysosomes, peroxisome, and glyoxysomes are derived from Golgi complex.
- During cell division in plants, it also gives rise to vesicles which contain all cell wall synthesizing materials.
- At cytokinesis, these Golgi-vesicles are arranged on cell equator, fuse to form **phragmoplast.**
- Phragmoplast gives **rise to cell wall.**
- Most of its **secretions** are **protein** nature.
- It collects these from RER through SER modifies them to perform specific function & then export these modified products in the form of vesicles.



# VACUOLE

- ***Single membranous organelle*** found in both plant and animal cells.
- In animal cells many small peripheral vacuoles are present.
- In mature Plant cells, large central vacuole is present that is formed by coalescence of smaller vacuoles during plant's growth and development.
- Membrane of vacuole that separates vacuole content from is called **tonoplast.**
- Vacuole plays important role in **maintaining turgor pressure** that provides mechanical support to the individual plant.
- Vacuole is storing house of water, cell products or metabolic intermediates.




Plant Cell Vacoule

parts of bone.

- Extracellular digestion also ta[kes] place in fungi.
- Tail of human embryo and tail o[f] tadpole is remo[ved] by **autolysis.**
- **Crinophagy :** Excess of hormo[nes] of Endocrine gla[nds] are digested by lysosomes
- **Glycogenesis typ[e] II** diseases are caused due to absence of D-glycosidase.
- GSD (Glycogen storage Disease) may be treated b[y] taking small meal[s] of Carbohydrates
- In USA, one child per **25000** births has GSD.
- Tay Sach's diseas[e] is due to absence beta-hexosaminidase.

## BTB

- Some tubules and vesicles may also participate in the formation of Gol[gi] complex.
- In plants, Golgi bodies are known **dictyosome.**
- Number of cisternae are **3-**[...] in most of animals but up to **30** in lower organisms.
- Forming face is closer to nuclear membrane. Maturing face is

**PTB**

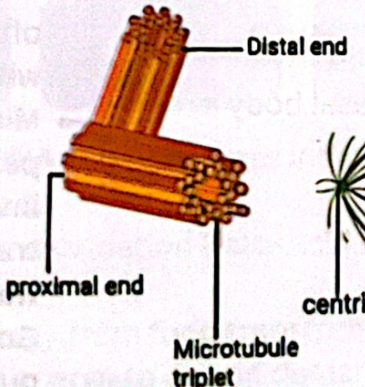
- In mature plants, vacuole is central and pushes remaining organelles in peripheral position.
- Vacuoles serve the plant by expanding its cytoplasm without diluting the cytoplasm.
- It also plays role in providing the rigidity to the leaves and younger parts of the plants.

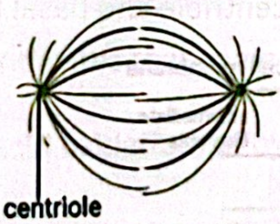
**FTB**

- Vacuoles are **large vesicles that originate from ER, Golgi complex and plasma membrane.**
- In animals, during intracellular digestion, food vacuoles are formed by phagocytosis.
- Many freshwater protists, have **contractile vacuoles** that pump excess water out of cell and maintain suitable concentration of ions and molecules inside it.
- In young plants, many small vesicles are present that hold reserves of important organic compounds.
- They also help in the protection of plants against herbivores by storing compounds that are poisonous and unpleasant for animals.
- The solution inside the central vacuole is called **cell sap.**
- Cell sap also contains reservoir of inorganic ions like potassium and chloride.

## CENTRIOLE

- **Non-membranous organelle & two in number.**
- **Nine triplets of microtubules** are found in cylindrical arrangement at right angle to each other exterior to nucleus.
- Each microtubule is composed of **3 tubules.**
- Found in animals and lower micro-organisms such as fungi like protists, slime Molds and water molds.
- **Absent in higher plants.**
- They become double just before cell division & one pair migrate to the opposite poles of nucleus.
- The spindle then forms between them by using centrioles as MTOCs (microtubule organizing centre) located outside nucleus.
- Involved in cell division and formation of cilia and flagella
- Whole structure of spindle fibre is known as **mitotic apparatus** (helps in distribution of chromosome between daughter cells during cell division).




farthest face closer to plasma membrane.

- Formation of acrosome during spermatogenesis
- Formation of egg vitelline membrane is also done by Golgi apparatus.

**KPK**

- Sometimes, polysaccharides may be synthesized from simple sugar in Golgi bodies.
- Secretory vesicles produced by Golgi apparatus add surface area to cell membrane.

**BTB**

- Diameter of centriole is **10 nm.**
- Centrioles were discovered by **Benden** in **1883** and **Boveri** in 1895.
- Centrioles are **self-replicating** units.
- Basal bodies of cilia and flagella are types of centrioles.

**BTB**

- The cytoplasm which surrounds centrioles is called centrosphere.
- Centrioles and centrosphere are together called centrosome.

**PTB**

- Centrioles also play role in location of furrowing during cell division.

**FTB**

- Centrioles are about 0.15 – 0.25 μm in diameter.
- 0.3 – 2 μm in length
- Centrioles also give rise to basal bodies or kinetosome of cilia and flagella.

# CYTOSKELETON

- Cytosol contains fibre network called **cytoskeleton.**
- Main proteins present in it are tubulin (microtubules), actin, myosin, tropomyosin & others that are also find in muscles.
- It contains three types of fibres:

Cytoskeleton
- Microfilament
- Microtubule
- Intermediate filament

## MICROFILAMENT (ACTIN FILAMENTS)

- Made of contractile actin protein.
- Occur in bundle or mesh-like network.

**PTB**

- More slender, linked to the inner surface of plasma membrane.
- Involves in internal cell motion.
- Amoeboid or cyclosis movement is also due to microfilament.

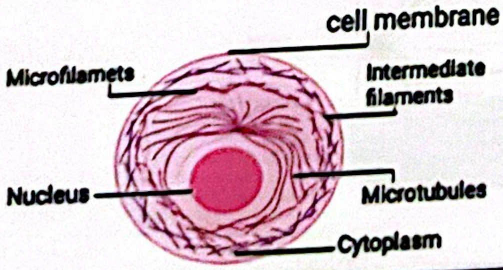


**FTB**

- *Microfilament is of 7nm diameter.*
- *Four twisted chains.*
- *Two chains of F- actin and two chains of tropomyosin and triplets of troponin at regular intervals.*
- *They form microfibrils in muscles.*

# MICROTUBULE

- *Long, unbranched, slender, tubulin protein structure.*
- *Plays role in assembly and disassembly of spindle structures during mitosis.*
- *Involved in formation of mitotic apparatus in plant cells.*
- *Involved in formation of cilia, flagella, centriole and basal body in animal cells.*




**KPK**

- Centrioles are a hollow cylinde (about 0.3-0.5 long & 0.2 μm diameter)

**BTB**

- Cytoskeleton is unbranched cylindrical structure.
- Microfilaments involved in:
- Muscle contrac
- Change in cell shape
- Division of cytoplasm durin cell division

**KPK**

- Koltzoff in 1928 suggested the existence of Fib network Later, **Cohen** (19 confirmed his vi by electron microscopic stu

**BTB**

- In plants microtubules are often associated with cell wall.
- Microtubules perhaps are involved in the transport of cell wall materials fr Golgi bodies to outside of cell.

**FTB**

- **0.2 – 0.25 μm** in length & **25 nm** in diameter.
- Tubulin is a dimer.

## INTERMEDIATE FILAMENT

- Involved in determination of cell shape and integration of cellular compartments.
- They have size in between microtubule and microfilament.

**FTB**

- **8 – 10 nm** in diameter.
- Contains **vimentin protein.**
- Each intermediate filament contains three chains of vimentin twisted around each other with no hollow space.
- It forms a network in cytoplasm which provide mechanical support to nuclear envelope and plasma membrane.

**BTB**

- Intermediate filaments assemble and disassemble & thus play important role in maintaining cell shape, attachment of muscle cell, support of nerve processes i.e. axon.

## MITOCHONDRIA (POWER HOUSE)

- It is found in **all eukaryotic cells.**
- Site of cellular respiration
- Role in production of ATP from ADP.
- Self-replicating organelle.
- Varies in number from cell to cell and also in shape and internal structure.
- **Consists of Two membranes:**
- Outer smooth layer.
- Inner membrane forms infoldings (**cristae**) into the inner chamber called mitochondrial matrix.
- Cristae consists of (bear) pin head particles called $F_0$-$F_1$ particles.
- It is also called oxysome, ATP synthase, stalked, elementen or fernandas-moran particles.
- Matrix of mitochondria consists of large number of enzymes, many coenzymes, organic and inorganic salts which help in vital metabolic processes.

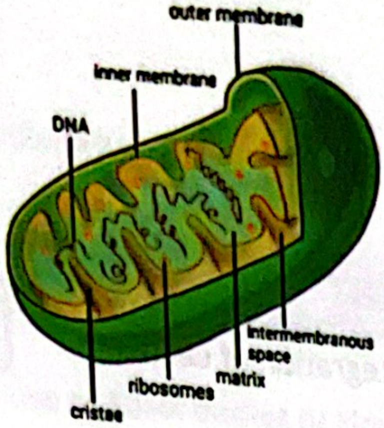


Mitochondrial Matrix
- dsDNA (Small & circular)
- All kinds of RNA
- Ribosomes (70s)
- Enzymes

- Presence of **DNA** and ribosomes indicates that some proteins are synthesized in it.
- **Kreb's cycle** and oxidation (fatty acid oxidation) of pyruvate occurs in mitochondria.
- Extracting energy from food transformed into energy rich compound ATP (provides energy to cell on demand).

**BTB**

- Mitos means thread; chondrion means granules.
- **Altman (1890)** established them as cell organelle and called them **bioblast.**
- The term mitochondria are given by **C. Benda (1898).**
- Diameter is **0.2-1 μm** & length **1-4.1 μm.**
- All the mitochondria present in a cell are called **chondriome.**
- Animal cells have greater mitochondria than plant cell.
- If outer membrane of mitochondria is removed, it is called **mitoplast.**
- Cristae increase surface area for chemical reaction.
- **1%** of total DNA is




**PTB**

- Under electron microscope appears as complex structure.
- Under Compound microscope they appear to be vesicles, rods or filaments.
- Membrane enfolding or cristae is made of **lipoprotein.**
- Mitochondrial membranes are similar in structure to other cell membrane.
- Size and number of mitochondria varies and depends on the physiological activity of cells.

**FTB**

- It is a cylindrical or rod shape structure.
- Some cells have one mitochondrion but more often cells have 100s or even thousands of it (e.g. cells that move or contract have more mitochondria than less active cells).
- Outer membrane contains **porin protein** that it can exchange material freely and is freely permeable.
- Inner membrane is semi-permeable.
- It divides the mitochondria into two compartments.
  1. **Intermembrane space** (narrow region between inner and outer membranes)
  2. **Mitochondrial matrix** (enclosed by inner membrane).
- Inner membrane also has several complexes that serves as electron carriers in ETC.
- Have its own metabolic machinery.

**Other names for mitochondria**

- ATP mill in cell
- Cell within cell
- Cell furnace
- Storage batteries
- Most busy and active organelle in cell
- Semi autonomous cell organelle



## PLASTIDS

- Plastids are **pigmented organelles** found only in plant cells and algal cells.
- Plastids are **double membranous organelles.**
- Plastids are of **three types:**
- All these three types made of are their precursors called pro plastids which are young, immature and developing plastids.

- present in mitochondria.
- This DNA is sma circular and can code the synthe of some type of proteins.
- Mitochondria als help in **vitellogenesis (y formation) in oocyte.**
- It is believed tha mitochondria ha endosymbiotic origin from **purp sulphur bacteri**

**KPK**

- Mitochondria ar absent in in mat **RBC** of human.
- Mitochondria w first seen in Mu cells in **1850.**
- Young one gets its mitochondri from its mothe (eggs).

**BTB**

- Plastids are the sites of manufacture an storage of important chem compounds.
- Most plants inhe plastids from on parent.
- **Example:** Angiosperms inh

# 1.CHLOROPLAST

- Membrane bound green pigment containing organelle with small granules.
- Green pigment is chlorophyll that absorbs light energy and utilize it to make food.
- Discoid structure & Self-replicating.
- Responsible for photosynthesis.
- Light reactions on thylakoid membrane and dark reactions occur in stroma of chloroplast.

**Parts of chloroplast (under EM microscope)**
- Envelope (formed by smooth double membrane)
- Stroma (covers most volume & surrounds thalakoids)
- Thylakoid (double membranous sac &flattened vesicles)

- Thylakoids pile up to form grana and inter-grana.
- **25 – 50** thylakoids form grana (green part) & there are **40-60** grana found in each chloroplast.
- Inter-grana is non-green part.
- Membrane of the thylakoids involved in the formation of ATP.

**PTB**

- Chlorophyll molecules have $Mg^{+2}$ as its central atom unlike
- haemoglobin which has $Fe^{++}$.
- Diameter is **4 – 6 µm.**
- On average there are **50** or more thylakoids piled to form one granum.
- On the layers of thylakoids chlorophyll molecules are arranged that is why granum appears to be green.
- Stroma consists of protein, ribosome (**70S**) and small DNA (**circular**) and various enzymes.



**FTB**

- Outer membrane has poring proteins.
- Inner membrane is rich in protein, and it is semi-permeable.
- Inter-grana are larger than grana.
- Stroma is a colourless, proteinaceous structure.

**Thalakoids**
- Smaller
  - Form granum
  - Have Photosynthetic pigments
- Larger
  - Form Intergranum (lamella)
  - Colourless

## 2. CHROMOPLASTS

- They impart colour to plants **other than green.**
- They are found in **petals of flowers.**

plastids from female gamete, while many gymnosperms inherit plastids from male pollen.

- Chloroplasts are green plastids and found in green parts of plants like leaves, herbaceous stems & unripened fruit coverings.
- The most important and abundant enzyme is **rubisco** (about **16%** of chloroplast)
- Semi-autonomous organelle.

**KPK**

- Under light microscope chloroplast appears to be heterogenous structure with small granules known as grana embedded in matrix.
- Stroma covers most of the volume of chloroplast.

**BTB**

- Chromoplast also contains chlorophyll but in a very less amount.
- There are up to **40** chloroplasts in a cell.
- Chloroplast originated from cyanobacteria through endosymbiotic process.

- Also found in ripened fruits.
- Help in pollination and dispersal of seeds.

## 3. LEUCOPLASTS

- They are colourless, plastids.
- They are found in underground parts of plant like roots, stem in parenchyma cells etc.
- They help in storage of compounds.
- They are triangular, tubular or some other shape.

Leucoplast → 03 types
- Elaioplast → Store lipids
- Amyloplast → Store starch
- Proteinoplast or Eluroplast → Store protein

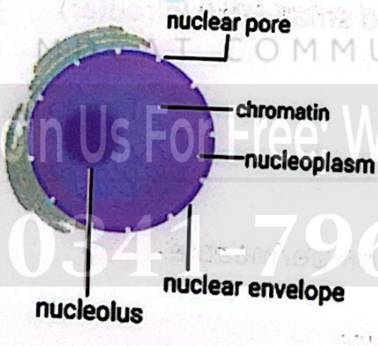
## NUCLEUS

- Discovered by Robert Brown in **1831** in an Orchid cell.
- Nucleus is the central part in animal cell (exception of muscle cells) and in plant cell it is peripheral (due to large central vacuole)
- It may be spherical, oval elongated or irregular shape.
- It is composed of **DNA, RNA** & **Proteins** including enzymes.
- It is visible only when cell is in non-dividing stage.
- It contains chromatin network & soluble sap (nucleoplasm).
- In dividing cell, it disappears, and chromatin material is replaced by chromosomes.
- Generally, each cell contains one nucleus (**mono-nucleated**) & sometimes may be two (**bi-nucleated or di-karyotic**) or many (**poly-nucleated**).

**BTB**
- Nucleus is self-replicating organelle.
- It is also called controller, hea[d] brain of cell.

Both the nucle[ar] membranes ar[e] separated by [a] nuclear space (**10-50nm**).

**KPK**
- Diameter of nu[cleus] = **10 μm**.
- Pigeon has 80 **chromosomes**



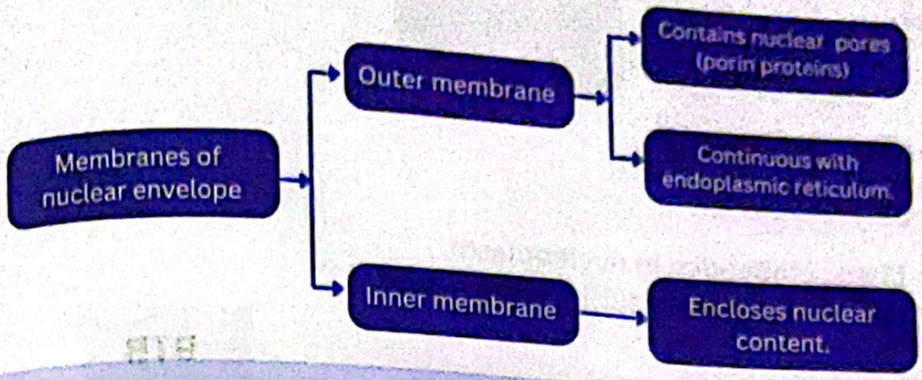



- **For example:**
  - Muscle cell contains many nuclei.
  - Paramecium is dikaryotic.
  - Opalina is multinucleated.
  - Nucleus is absent in some cells like:
  - In mature mammalian RBCs.
  - Mature phloem sieve tube elements in plants.
- **Nucleus consists of following structures:**

Nucleus
- Nuclear envelope
- Nucleoplasm
- Nucleolus
- Nuclear pores
- Chromatin
- Chromosomes
- Karyotype

## NUCLEAR ENVELOPE

- It separates the nuclear material from cytoplasm.




## NUCLEOPLASM

- Nucleoplasm is a transparent semi-fluid ground substance of nucleus which is also known as nuclear matrix or **karyoplasm**.
- It is transparent complex colloidal fluid contains water, proteins, enzymes like ATPase, **DNA and RNA** polymerase, endonucleases and ions like **$Ca^{++}$**, **$Mg^{++}$** (for DNA & RNA synthesis) etc.
- It also contains free nucleotides, histone and non-histone proteins.

## NUCLEOLUS

- Nucleoplasm also contains one or more nucleoli.
- Nucleolus is non-membranous which is spherical darkly stained.
- It is only visible during **interphase** while disappear during cell division.
- The main function of nucleolus is to form subunits of ribosomes.
- The rRNA is synthesized and stored here.
- Factory of ribosome in cell.

**BTB**

- Nucleolus usually attached to chromatin at specific site called **nuclear organizer region (NOR).**
- Nucleolus is **composed of 85%** proteins, **10%** RNA & **5%** DNA.
- Nuclear pores are also guarded by permeases in the form of a pore complex.

## NUCLEAR PORES

- Inner and outer nuclear membranes are continuous at certain points.
- Number of nuclear pores is highly variable & vary from cell to cell.
- Each pore has a definite shape.
- Nuclear pores control traffic of cell (allows the exchange of material).

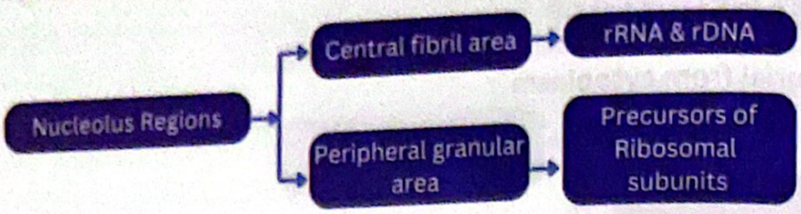


**FTB**

- It regulates nucleo-cytoplasmic exchange.
- **Exchange** includes RNA & ribosomal proteins moving from nucleus to **cytoplasm** & proteins (like DNA polymerase), carbs, signalling and lipids moving into nucleus.
- Smaller molecules simply diffuse through the pores.
- Larger molecules may be recognized by specific signal sequence and then be diffused with the help of nucleoporin into or out of cell.

**PTB**

- Undifferentiated cell has greater nuclear pores than differentiated cell
- Egg cell has **30,000 per nucleus**. While erythrocytes have **3 – 4** per nucleus.




- **rRNA & rDNA** are of large molecular weight.

## CHROMATIN

- Network of nucleoprotein fibers, embedded in nucleoplasm.
- Chromatin condensed to form chromosomes during cell division.

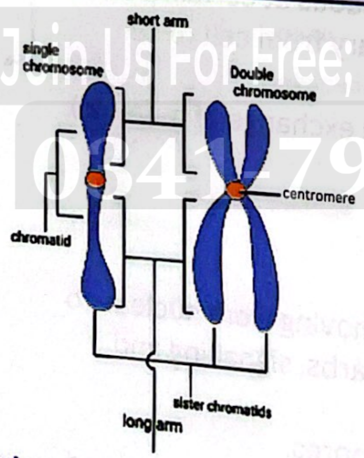
## CHROMOSOME

- **Darkly stained** thread-like structure made of DNA & Proteins.
- Chromosomes absorbs deeply in basic dyes during staining, thus darkly stained structure.
- **Under compound microscope** it appears to be made of arms and centromeres (spindle fibres are attached here during cell division).
- All the information important to control the activities of cell is located on the chromosome in the form of genes.

## KARYOTYPE

- Array of chromosomes.
- The number of chromosomes is definite for each species.

| Cell | Chromosomes | Cell | Chromosomes |
|---|---|---|---|
| Human | 46 | Chimpanzee | 48 |
| Onion | 16 | Maize | 20 |
| Pea | 14 | Frog | 26 |
| Sugarcane | 80 | Fruit fly | 08 |
| Mouse | 40 | Mucor | 02 |




- **Each chromosome has:**
- **Two identical sister chromatids** (exact replica of chromosome) at the beginning of cell division.
- Two sister chromatids connected together at a common point called **centromere**. (primary constriction)
- **Kinetochore protein** is present at centromere, during cell division.
- Chromosomes are the vehicle of hereditary material (genes) from parent cell to daughter cell.

**BTB**

- **Chromas:** colo... **Soma:** body.
- Chromatin co... of both histone (basic), non-hi... (acidic) protein, DNA, and little amount of RNA
- Chromosome ... be best studied ... **metaphase** sta... because size of the chromosom... shortest during metaphase
- Chromosome is covered by thin proteinaceous sheath called **pellicle.**

**PTB**

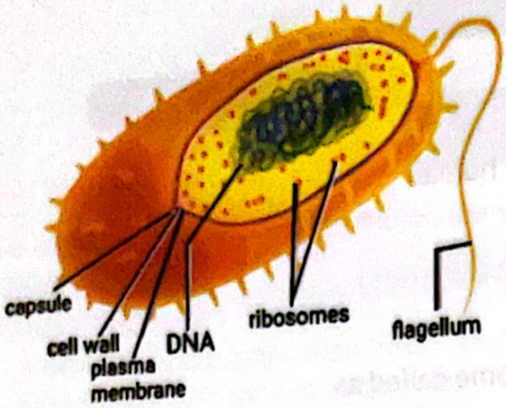
- Potato has **48 chromosomes.**
- Diploid cell = **2n chromosome.**
- Haploid cell = n chromosome. (present in germs cell) e.g. human sperms and eggs have **23**

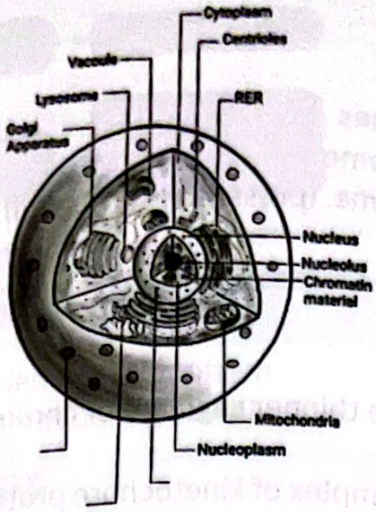
**FTB**

- Centromere lies within the thinner segment of chromosome called as **primary constriction.**
- Each centromere has a complex of kinetochore protein present on the opposite side of constriction.
- It forms the site of attachment of single microtubule during cell division.
- Some chromosomes may have another point of union along the length of chromatids called **secondary constriction or nucleolar organizer.**
- It gives rise to nucleoli during interphase.
- Ends of chromosomes are called **telomeres.**

## PROKARYOTES AND EUKARYOTES

| Prokaryotes | Eukaryotes |
|---|---|
| **1.** Pro: before; karyon: nucleus | **1.** Eu: true; karyon: nucleus **2.** Have distinct |
| **2.** Don't have distinct nucleus. | nucleus. **3.** Includes animals, plants, fungi |
| **3.** Includes bacteria, cyanobacteria (blue-green algae) and archaea. | & Protista. |
| **4.** Lacks membrane bound organelles like cytoskeleton, mitochondria etc. | **4.** All membrane bound organelles are present. |
| **5.** 70 S ribosome (50S + 30S) | **5.** 80 S ribosome (60 S + 40 S) |
| **6.** Nuclear material (DNA) is dispersed in cytoplasm. | **6.** Nuclear material (DNA) is within nucleus. |
| **7.** Consists of small, single, circular chromosome (having only DNA). | **7.** Consists of two linear chromosomes (having DNA, proteins, little RNA). |
| **8.** Histone is absent. | **8.** Histone protein is present. |
| **9.** Plasma membrane lacks sterols like cholesterol. | **9.** Plasma membrane does have sterols in it. |
| **10.** Divided by binary fission. | **10.** Divided by mitosis. (normal cells) Meiosis in germ cells. |
| **11.** Flagellin is part of flagella. | **11.** Tubulin is part of flagella. |
| **12.** Mesosomes are present. | **12.** Mesosomes are absent. |
| **13.** Prokaryote (bactria) cell wall is made of peptidoglycan (polysaccharide chains bounded covalently to shorter chains of aminc acid) / murein. | **13.** Plant cell wall is made of cellulose. Fungi cell wall is made of chitin. |




- Cell wall is the main distinctive feature between prokaryote and eukaryote.
- Prokaryotic cell wall is often referred as single huge molecular complex called **sacculus**.
- Eukaryotic cell have flagella or cilia made of microtubules.

## ORGANELLES FOUND ONLY IN PLANT AND ANIMAL CELLS

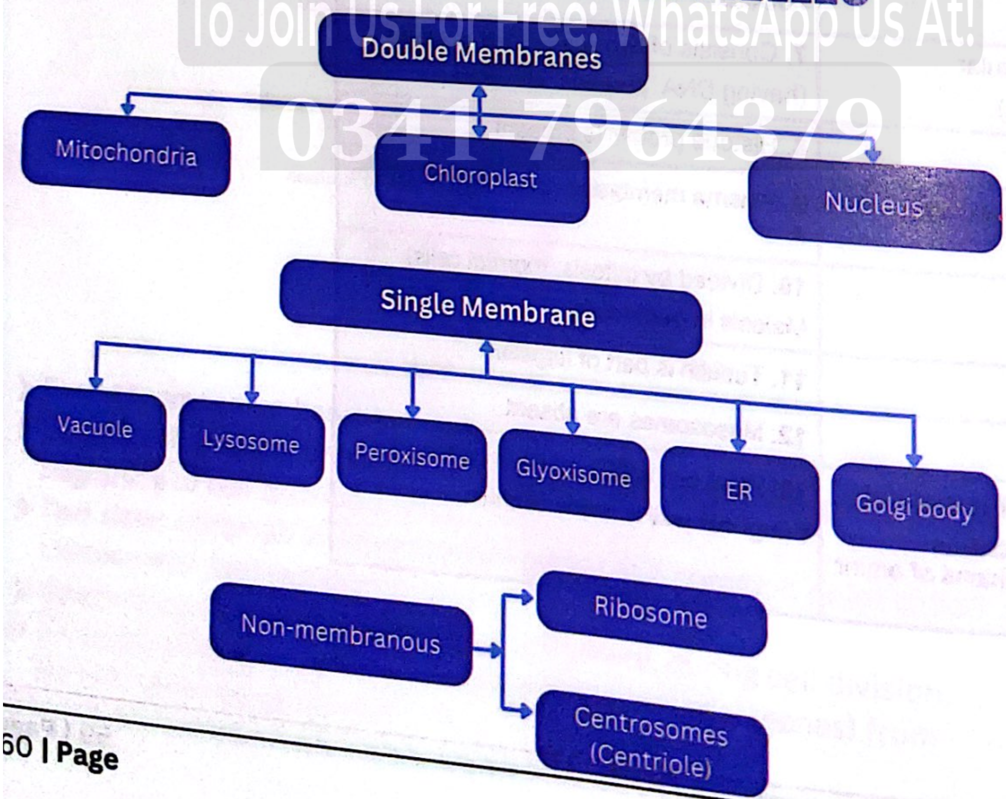
| Plants | Animals |
|---|---|
| 1. Plastid | 1. Centriole |
| 2. Central vacuole | 2. Peripheral vacuole |
| 3. Glyoxysome | |

**NOTE**

- Mitochondria, lysosome, peroxisome, ER, Golgi body, nucleus and ribosomes are found in both animals and plants.



## MEMBRANE BOUND ORGANELLES



# VIRUSES

## Introduction

- Word virus is derived from Latin word "Venom" means "Poison".
- Non-cellular infectious entities containing either RNA or DNA in a protein coat
- Reproduce only in living cell.
- They depend on host cell because they lack biosynthetic machinery
- Causes disease in plant and animal like influenza bird flu, dengue fever, swine flu.
- They don't follow cell theory.

**BTB**

The life form which exists without a cellular structure is known as A-cellular life.

- **Viruses and Viroids** are included in a-cellular life.
- **Viroids** are the smallest infectious agents consisting of circular single stranded RNA without protein coat.
- Viruses are non-living because they are not capable of **AUTOPOIESIS** (The ability of reproduction) without host.

**KPK**

- Viruses don't excrete

## HISTORY OF VIRUSES

- About a century ago, at the time of Louis Pasteur and Robert Koch, the word virus is referred as disease and death
- First infectious disease against which vaccination was used was viral disease.
- In **1796** Edward Jenner, first Vaccinated an eight-year-old boy with cowpox lesion after 6 weeks, he was inoculated with puss from a small pox victim.
- The boy didn't get the disease.
- As the material was from cow (Latin: vacca), Pasteur reformed this process as vaccination.
- Rabies → a disease caused by bite of dog, foxes' cats etc.
- Charles Chamberland:
- In **1884,** Charles Chamberland, found that organism or agents Responsible for rabies could pass through the porcelain filters of **(100-1000nm)** while filter can remove all bacteria or other cells from cell/liquid suspension.
- These agents were considered as filterable Virus.
- Iwanosky, in **1892**, he discovered that infectious entities responsible for tobacco mosaic disease is filterable.
- To examine, he extracted the juice from diseased tobacco plants and pass it through the filter to remove the bacteria, when the juice was applied on normal plants, they got disease
- W.M.Stanely: He crystallized the tobacco mosaic (T.M.V) in **1935**.
- The study of virus is known as virology.



**PTB**

- Yellow Fever → **1901**
- First Animal virus discovered which causes Foot and mouth disease in animals → **1898**

## CHARACTERISTICS OF VIRUSES

- Viruses are seen through electron microscope.
- Can pass through filter.
- Reproduce only in living cells.
- Occur in different stains.

- Contain either RNA or DNA and can undergo mutation.
- Destroyed by ultraviolet radiations.
- Lack cellular structure and enzymes.
- No metabolic activity of its own.
- Can be crystallized and stored in bottles.
- Non-living outside the organism.
- Resistant to broad range antibiotics like tetracycline etc

**PTB**

- Largest viruses are pox viruses **(250nm)**
- Smallest viruses are parvoviruses **(20nm)**.
- Cannot be grown on artificial media (glassware).
- Viruses have both living and non-living characters:

| Living | Non-living |
|---|---|
| 1. Have genetic material | 1. Non-cellular. |
| 2. Undergo mutation. | 2. Lack enzymes and coenzymes. |
| 3. Reproduce inside host cell by using host machinery. | 3. Can be crystallized and stored in laboratory. |
| 4. Destroyed by UV radiations and chemicals. | 4. Don't respire and use energy of host. |
| 5. Occur in different strains. | 5. Have ambivalent (fluctuating) nature. |

- Viruses behave as non-living, inert infectious particles outside the host. Due to these properties, viruses are considered as **boundary line between living and non-living**.



## STRUCTURE OF VIRUS

- Complete and mature virus is known as **VIRION**.
- Composed of two parts primarily:
  1. **CORE**
  2. **COAT**



**CORE:**

The core is the inner part of the virion includes the viral genome and various proteins (enzymes).

- Genome is the genetic material, which is either DNA or RNA, which may be single stranded or double stranded.
- Core proteins include one or more enzymes that facilitate the virus in its mode of action inside host.

**COAT:**

The coat is the outer covering of viral particle which consist of capsid and envelope.

- The capsid is protective coat of protein outer to the core. Capsid is made of identical repeating subunits called capsomers **(capsomeres)**.
- Capsid gives definite shape.
- No. of capsomeres is specific for each virus.
- There is an additional lipoprotein covering derived from host cell membrane called envelope.

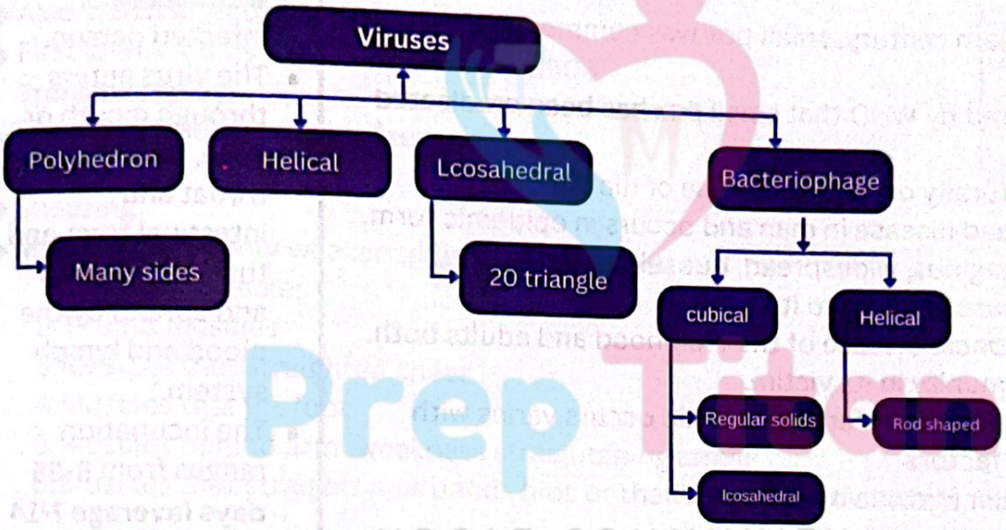
- Envelope is external to capsid
- The viral envelope is often covered with glycoprotein spikes that help them to recognize the host cell.

| Virus | Capsomeres |
|---|---|
| Herpes | 162 |
| Adeno | 252 |
| Ambidenso virus | 60 |
| Polio Virus | 32 |

- Genome + capsid =nucleocapsid
- Non enveloped viruses are also known as naked viruses are more resistive to antibiotics than enveloped viruses

**PTB**

- There are different forms of animal and plant viruses:




- Many phages consist of head and tail.
- Head is polyhedral but tail is rod shaped.
- Bacteriophages are viruses that eat or infect bacteria.
- They are discovered by Twort in **1915** and D. Herelle in **1917** independently.



**PTB**

- Retroviruses and hepatitis B have reverse transcriptase that converts single stranded RNA into double stranded DNA.
- Polio virus has **32 capsomeres**.
- Virus envelope is also covered by glycoprotein spike (to recognise host cells).

## SOME COMMON VIRAL DISEASES

| Diseases | Agent | Description | Symptoms |
|---|---|---|---|
| 1. Small pox | Pox virus | DNA enveloped | Raised fluid filled, latter pustules and then pocks. |

**KPK**

- Influenza virus exists in different shapes from round balls to long, spaghetti-like filaments.
- **Corona virus:** (COV)
- "COV" is ssRNA enveloped virus.
- Cause illness ranging from common cold to more severe disease such as middle east respiratory syndrome (MERS-COV) & several acute respiratory syndromic (SARS-COV).
- **Noval COV (nCOV)** is new strain that has not been previously identified in humans,
- Incubation period: For **COVID-19** range from **1-14 days** most common around **5 days**.

**KPK**

- Virus abundant in nature composed of macromolecules
- Composed by the organism they infect.
- Virus affects living organism from Bacteria to mammals
- In ten minutes, virus control over

# HEPATITIS (INFLAMMATION OF LIVER)

It is caused by viral infection, drugs toxic agents.

| | | | | |
|---|---|---|---|---|
| Hepatitis A (Infectious) | Picornavirus (HAV) RNA Non-enveloped virus | Oro-faecal route, contaminated water, food etc. | Acute infection (recent infection) Nausea, Vomiting, Diarrhoea, Jaundice. Fever, Loss of Appetite Dard Urine | Vaccination / Good Hygiene |
| Hepatitis "B" (Serum hep.) | HBV (Headman-virus) DNA enveloped virus | Blood, sexual contact, Mother to newborn saliva etc. | Acute (vomiting, yellowish skin, trended, dark urine, abdominal pain) & chronic (no symptom, liver-cancer, liver-cirrhosis) | Vaccination/ Alpha interferons/ screening of blood |
| Hepatitis C (Infusion hep.) | HCV (Flavin virus) RNA enveloped virus. | Only Via Blood, Sexual Contact | Chromic (Occasionally fever, dark urine, abdominal pain, yellowish skin, cirrhosis, liver cancer) | No Vaccination / Alpha interferons, Riba Visin, Screening of Blood |
| Hepatitis D (Delta hep.) | HDV (Viroid's) RNA Enveloped | Blood or serum | Same as Hepatitis B | Same as Hepatitis B |
| Hepatitis E | HEV (Picorna virus) RNA non-enveloped | Oro-faecal route contaminated water food etc. Pig could be source of Hep.E | Acute infection (Nausea, Vomiting, Diarrhoea, Jamaica) | Vaccination/ Good Hygiene |



# AIDS (ACQUIRED IMMUNO DEFICIENCY SYNDROME)

The Aids was first reported in young male homosexuals in early **1980**.
It is caused by HIV (human immunodeficiency virus).
HIV was discovered by Pasture institute in France and National Institute of Health in USA in **1984**.
HIV named in **1986**.

**BTB**

- HIV belong[s to] family retrov[irus] and genus lentivirus.
- HIV screening is done by EL[ISA]. PCR is more authentic th[an] ELISA.
- Red Ribbon is symbol for solidarity with patients.
- **1st December** world AIDS d[ay]
- There are two species of HIV
- **HIV-1** (most common pathogenic st[rain])
- **HIV-2** (it is not widely recogn[ised] outside Africa)

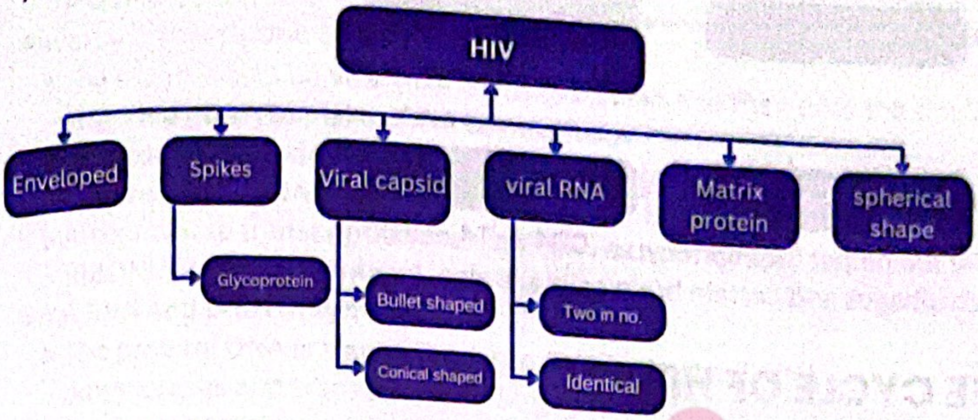
**KPK**

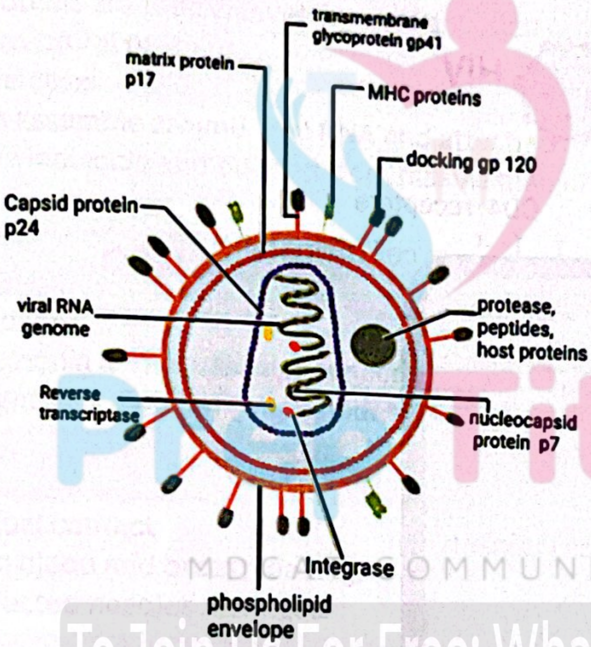
- An HIV particle around **100-1[50] billionth of a** [meter] in diameter.
- That's about t[he] same as micro[...]
- **4 millionths of inch**
- **One twentieth** length of E. co[li]
- **One seventie[th]** diameter of h[uman] **CD4** white blo[od] cell.
- HIV is surrou[nded] by **72 little s[pikes]**
- **P17** forms th[e] matrix
- **P24** forms t[he]

- The major call infected by HIV are Helper T-lymphocytes, major cells of immune system.
- The infection decreases the Helper T-cells and person becomes susceptible to other diseases.

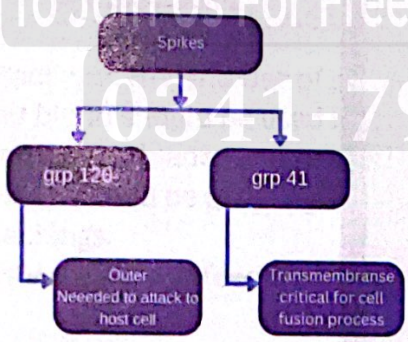
## STRUCTURE OF HIV

- Structure of HIV





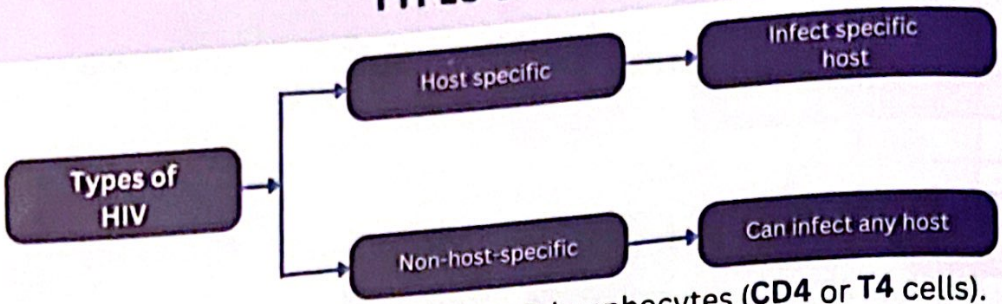

- The HIV is spherical in shape.
- The HIV capsid is conical in shape, which is composed of capsomeres.
- The matrix proteins lie between the envelope and capsid.
- The viral core contains two single strands of Viral RNA and the enzymes needed for viral replication process.

**ENZYMES:**

- The reverse transcriptase enzyme is used to make convert viral RNA genome to Viral DNA.

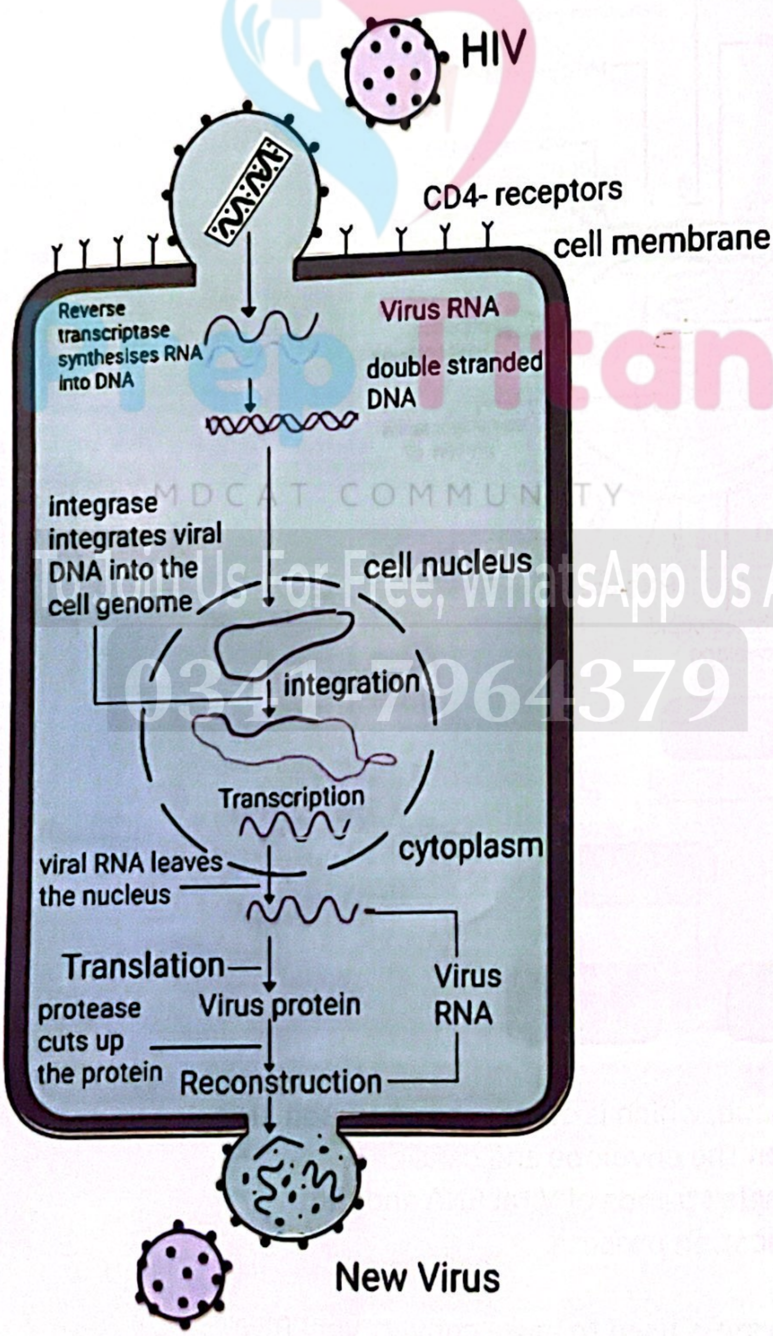
- The integrase enzyme is used to incorporate viral DNA into Host DNA
- The protease enzyme is used to break large structural proteins to smaller units.
- These structural proteins are encoded by **3 out of nine virus genes.**

## TYPES OF HIV




- The primary hosts of HIV are helper T-lymphocytes (**CD4** or **T4** cells).
- In addition to that, macrophages and certain brain cells are also affected.

## LIFE CYCLE OF HIV



**Attachment, entry, and uncoiling:**

- The initial step involves the attachment of which is characterized by binding of virion gp120 receptors to CD4 receptors.
- Next the fusion takes place with the cell membrane and virus enters the cell through endocytosis.
- The virion enters the host cell at CD4 receptor site and is uncoated inside the host cell.

**Reverse Transcription and Integration:**

- The enzyme acts on viral RNA to make a cDNA and then uses the single stranded cDNA to make cDNA double helix.
- This double stranded cDNA then enters nucleus and integrates into chromosomal DNA of the host as a provirus by Integrase enzyme.
- After reverse transcription the viral RNA is disintegrated by RIBONUCLEASES (RNAase).

**Viral RNA and protein synthesis:**

- The proviral DNA is transcribed into RNA by host cell RNA polymerases and translated into large proteins by host ribosomes.
- The large proteins are then cleaved by viral encoded proteases to make viral structural proteins.

**Assembly and release:**

- New capsids assemble around viral RNA and attached reverse transcriptase molecule and budded from plasma membrane by exocytosis.

## COMMON SYMPTOMS

- Fever & Headache
- Severe pneumonia & Rare vascular cancer
- Sudden weight loss, Swollen lymph nodes & Loss of immunity

## CAUSES

- Intimate sexual contact
- Contact with blood and breast feeding.
- Common infected needles /syringes.

## CONTROL MEASURES

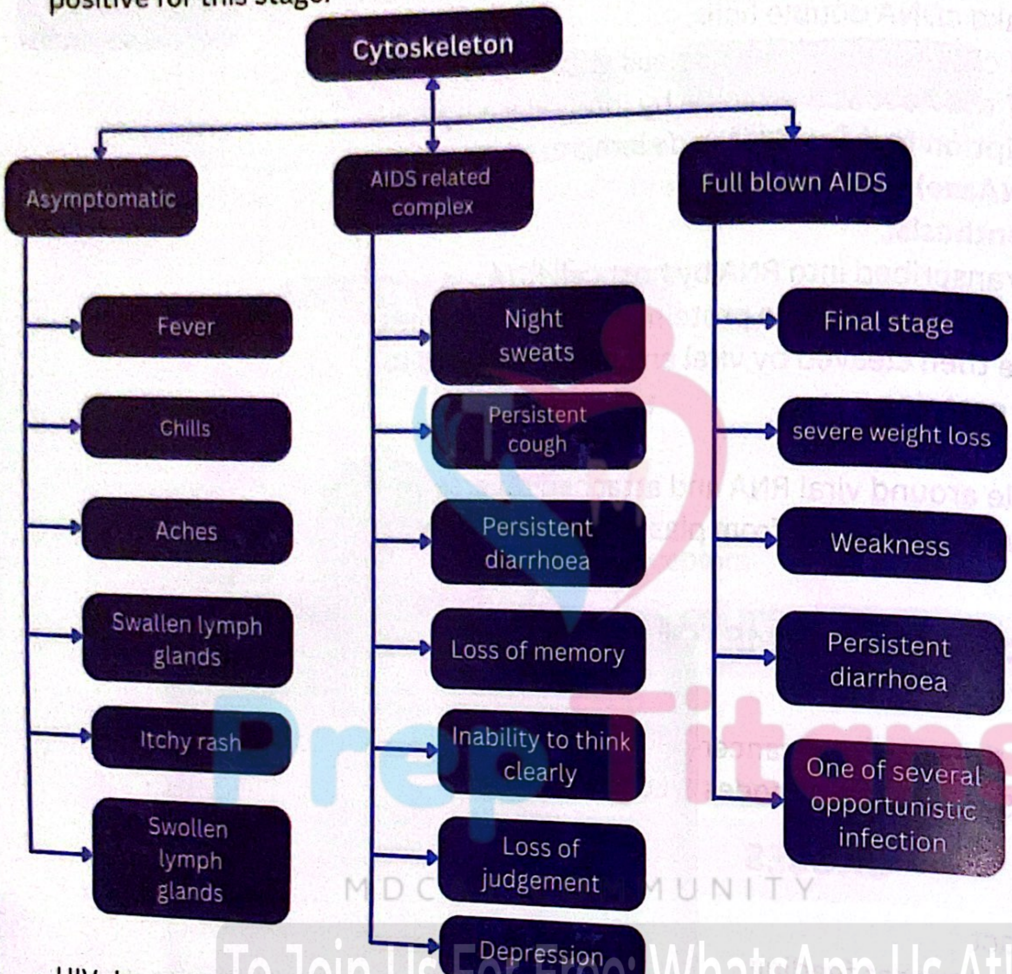
- Avoid direct contact with HIV and Use of sterile syringes.
- Properly screened blood should be used for blood transfusion.
- Don't share toothbrushes, blades and towels.
- Surgical instruments should be properly sterilized.
- Follow Islamic teachings.
- Mothers having HIV should not feed their babies.

**PTB**

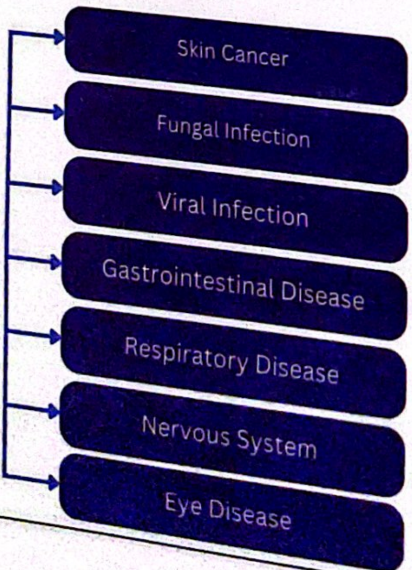
- HIV is the most familiar retrovirus (tumour). Its diameter is **100nm**.
- HIV also affects cells of CNS.
- Studies reveal that HIV infects and multiplies in monkey also but does not cause disease that shows that it is host specific.
- Now vaccine against HIV has been synthesized and experimental administration in humans started in early **2001** in South Africa.
- Proviral DNA is double stranded DNA.

FTB

- Envelope of HIV is made of lipoprotein.
- During HIV, host cell size is decreased and it becomes non-functional.
- Following are **symptomatic stages of AIDS:**
- These symptoms disappear and there are no symptoms for 9 months or longer.
- The standard test for HIV for the presence of antibody becomes positive for this stage.




- HIV does not cause any disease nor kills any person
- It only destroys nervous system and several opportunistic infections attack body.
- For example, Kaposi's sarcoma (cancer or lesion on skin). Other opportunistic disease involve;




BTB

- There is curr
no cure or va
to prevent H
- A treatment h
**active antivir**
**therapy (HAA**
given but no
improvement
observed.

- The aim of HIV treatments is to reduce viral load (the quantity of virus at which it is detected in an organism).
- The decision to start therapy is major one.
- HIV is treated using antiretroviral therapy (ART)
- ART is not cure, but it can control the virus so that person can live a longer.
- But ART is often costly and daily pill taking reduces quality of life.
- Shaking hands, hugging, coughing, sneezing and swimming in the same pool do not transmit HIV.
- AIDS is not transmitted by mosquitoes and other insects.
- **FACTS**
- **36.7 million** people were living with HIV in **2015**.
- **35 million** people have died from Aids related illness in **2015**.
- Every year **1.9 million** adults becomes infected with HIV.

# CLASSIFICATION OF VIRUSES

➤ Classification of viruses is of three types:

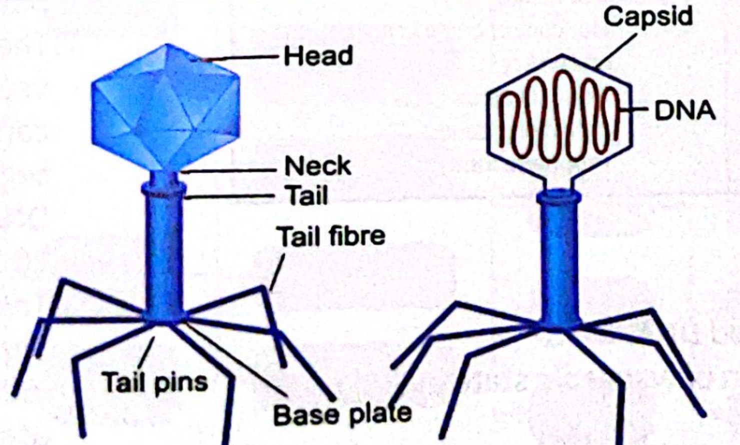
Basis of classification
- Morphology
- Genome
- Host

## DEPENDING UPON MORPHOLOGY

Morphology
- Tadpole like
  - Bacteriophage
  - Complex morphology
- Polyhedral capsid
  - Adenovirus
  - Spikes at each vertex
- Helical capsid
  - TMV
  - Rod shaped
- Complex enveloped capsid
  - Surrounded with spikes
  - Influenza virus
- Bullet shaped
  - V-shaped capsid
  - HIV



## STRUCTURE OF BACTERIOPHAGE

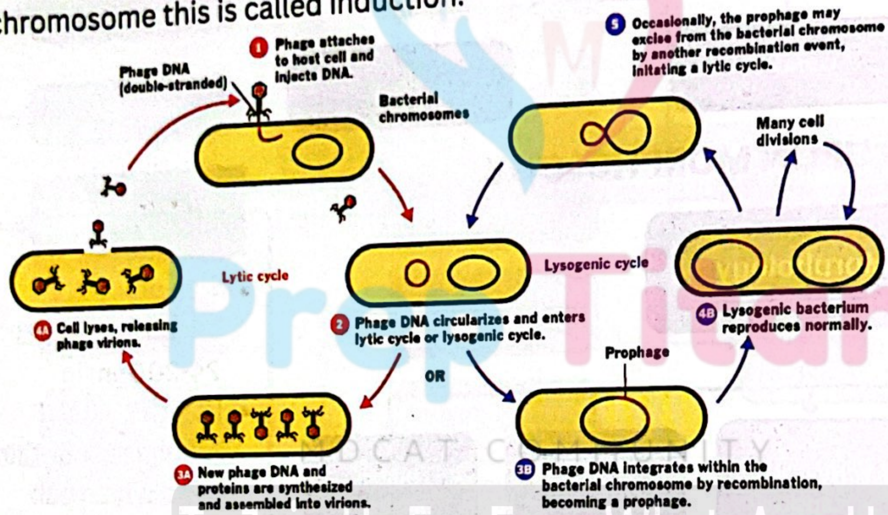



**KPK**

- Size of bacteriophage is **24-200nm** in length.
- All phages contain a head which can vary in shape and size.
- Many but not all phages have tails attached to the phage head. The size of tail can vary and some don't even have a tail. Not all bacteriophages have a base plate and tail fibres. In these circumstances, other structures are used for attachment to bacterial surfaces.

## PTB

- Bacteriophage infects in the following way:
- Landing → attachment (adsorption) → tail contraction → penetration and unplugging → DNA injection.
- Receptor site is present on the cell wall of bacteria where bacteriophage attaches.
- Tail releases lysozyme enzyme to dissolve a portion of bacterial cell wall for injection.
- Protein coat remains outside the host cell.
- Animal viruses enter host cell as a whole.
- The volume of the phage is about **1/1000** of the host.
- About **25 minutes**, approximately **200** new phages are released to infect new viruses.
- The phage which causes lysis of host cell is called lytic cycle or master slave relation.
- The phage which causes lysogeny (viralDNA + bacterial DNA) is called temperate or lysogenic phage.
- During lysogenic cycle, when viral DNA detaches from host chromosome this is called induction.




| Lytic cycle | Lysogenic Cycle |
|---|---|
| • Develop master-slave relationship.<br>• Bacterial cell burst.<br>• Also called virulent phage.<br>• Cannot divide, but multiplied its DNA and protein coat.<br>• No repressor protein.<br>• Not Resistant.<br>• Cell Destroyed.<br>• Control metabolic machinery.<br>• Infectious cycle.<br>• Lysozymes cause bursting.<br>• Prophage not formed. | • Develop Host-guest relationship.<br>• Remain intact.<br>• Also called temperate phage.<br>• Bacterial cell divide & viral DNA also multiplied.<br>• Repressor protein present. (inactivate viral DNA).<br>• Bacteria develop resistance.<br>• Not destroyed.<br>• Not control on metabolic machinery/<br>• Non-infectious cycle.<br>• Induction occurs.<br>• Prophage formed. |

## FTB

- Bacteriophage has single stranded DNA.
- Condition that favors termination of lysogenic state include:
- Desiccation

## BTB

- Bacteriophage ubiquitous vir found whereve bacteria exist.
- It is estimated number of bacteriophage more than any other organism earth.
- The number of genes in bacteriophage genome varies few to over 10 **genes**.
- The **NECK** of bacteriophage narrow area of without sheath is attached to h
- The bacterial b plate has enzym lysozyme which digests the cell of bacteria.

**USAGE OF BACTERIOPHA**

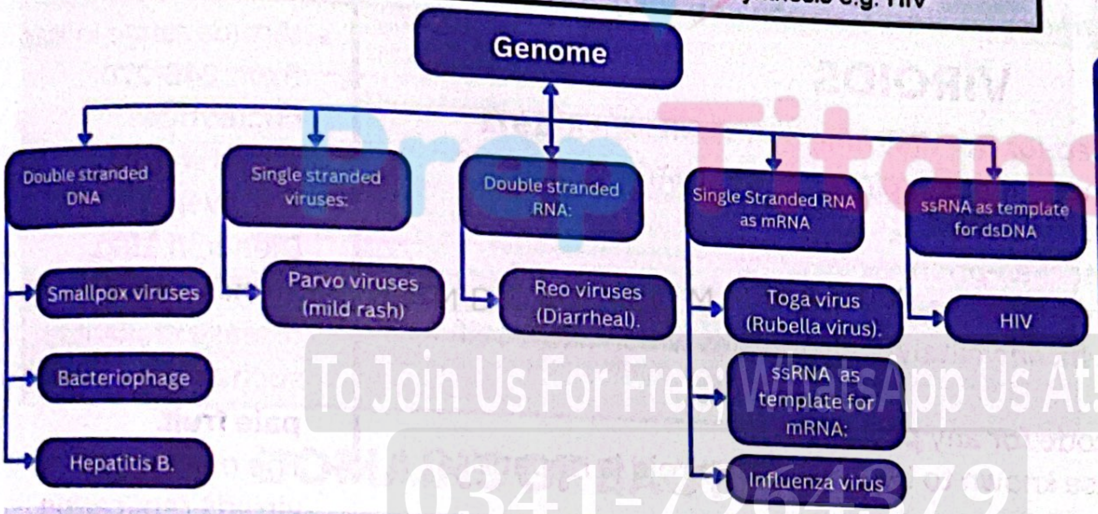
1. They are us VECTORS al with plasmi genetic engineering. bacteriopha called lamb more efficie than bacteri plasmids.
2. The phage vectors can carry larger segments of DNA usually 20 base pair
3. The virus enzymes ho and lysins a used to deg

- Exposure to UV or ionizing radiation.
- Exposes to mutagenic chemical, either spontaneous or environmentally included, excision.

## DEPENDING UPON GENOME

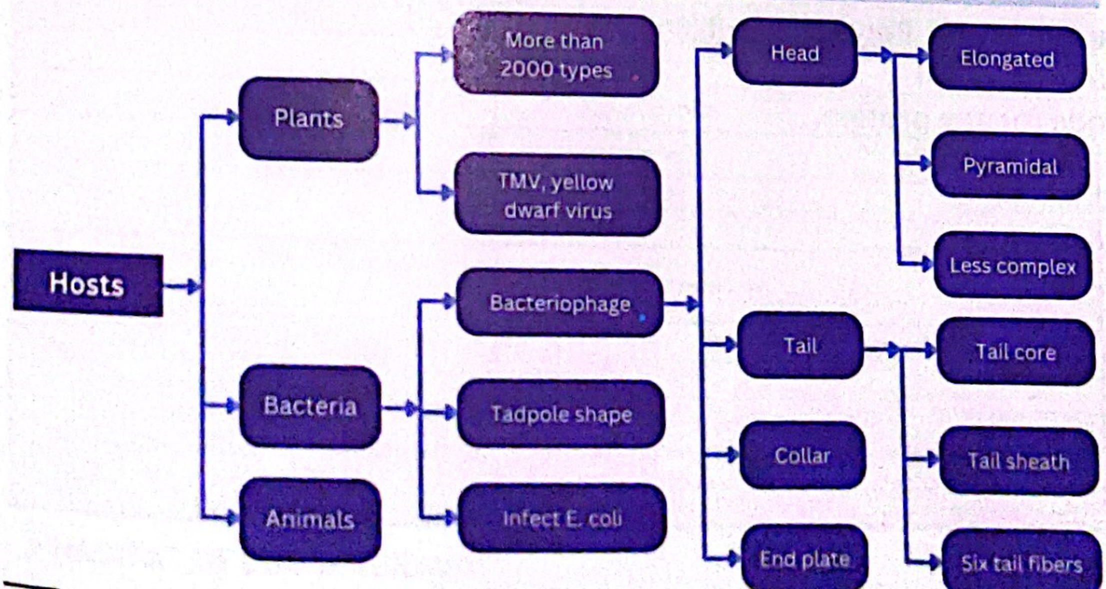
David Baltimore, a noble prize winner classified viruses into seven groups depending on their genome and mode of replication.

| | |
|---|---|
| dsDNA | Pox virus causes small pox, & cowpox virus, Herpes Viruses, Hepatitis, B-Virus, Adenovirus, Coli phage, Lambda Virus, Vertical Zoster, Bacteriophage (T2, T4, T6, T8) |
| ssDNA | Parvovirus, causes mild rashes, Bacteriophages (ϕ x 174, M13 and caliphate S13) |
| dsRNA | Reo Virus Causes → diarrhoea, Rice dwarf virus → wound tumar virus |
| ssRNA (+ve strand or sense) | Act as mRNA, Toga Virus (Rubella Virus), Hepatitis A and C, Corona or COVID (SARS, MERS), Dengue Virus. |
| ssRNA (-ve strand or sense) | Act as template for mRNA synthesis Orthomyxovirus (Influenza virus) Paramyxovirus, Rabies Virus, Ebola |
| ssRNA (-ve strand or sense) | Template for DNA synthesis e.g. HIV |






## DEPENDING UPON HOST




the bacterial cell walls so bacteriophages have proposed an alternative to antibiotics for many of the antibiotic-resistant strains.

**KPK**

- Prions are infectious, proteinaceous particles that contain no nucleic acid.
- These are smaller than viruses.
- Prions cause mysterious brain infections and mad cow disease.

**BTB**

- The cause of transmission of prions is mainly unhygienic feeding and contaminated food.
- Creutzfeld Jacob disease (CJD)
- KURU
- Fatal familial insomnia (FFI)
- These above diseases are due to prion transmitted by unhygienic way of feeding and contaminated food
- No effective treatment is available and always fatal.

## PRIONS

- Prions are proteinaceous infectious particles which cause neurodegenerative disorder.
- They affect human and other mammals.
- Loss of memory, paralysis and destruction of nerve tissues are symptoms of prion disease.
- No effective treatment is available and illness and progressive and fatal.

**PTB**

- Prions are the most recently discovered **(1983)**
- Least understood microorganisms.
- Their nature is very controversial.
- They are composed of proteins that code for their replication.

**FTB**

- Stanely Prussiner reported Prions.
- Prions are much more resistant to UV light and heat.
- Prions are composed of single glycoprotein and coded by single cellular gene.
- Fatal neurodegenerative diseases like KURU in HUMAN and in CATTLE mad cow disease (bovine spongiform encephalopathy).

**KPK**

- Scrapie or Bovine or mad cow disease is caused by prion
- It affects CNS of sheep or goats.

## VIROIDS

- Viroids were discovered for the first time by T.O DIENER in **1971**.
- Viroids are highly complementary, circular, single stranded RNA without a protein coat or envelope.
- Viroids are also smaller than prion.
- Viroids are plant pathogens.
- Viroids are ribozymes having catalytic properties which allow self-cleavage.
- Viroid RNA does not code for any protein.
- The only human disease known to be caused by viroid is Hepatitis D.

**FTB**

- The replication mechanism is RNA **Polymerase-II** (enzyme associated with synthesis of mRNA from DNA)
- Viroid RNA does not code for any protein.

**KPK**

- The first viroid discovered was the potato spindle tuber viroid (PSTV) which causes disease in potato.
- Viroids cause several plant diseases such as cadang disease of coconuts.

**BTB**

- Viroids range in size from **246-270** nucleotides.
- Viroid was first discovered by T.O Diener in **1971**
- Viroids cause disease in plants such as **cucumber pale fruit**.
- The mechanism of viroids replication is unclear so far.

# PROKARYOTES

## Introduction to Bacteria

- The Dutch scientist **Antonie van Leeuvenhoek** first discovered the Bacteria in **1674.** He called them Animalcules.
- **Ehernberg** named them Bacteria in **1882.**
- **Gk. Bacterion** means small staff or rod.

## CLASSIFICATION OF BACTERIA

The events in the discovery and classification of bacteria are explained below:

| Scientist | Achievement |
|---|---|
| A.V.Leeuwenhoek 1674 | 1st to report microbes (bacteria protozoa) in rainwater, than confirmed in saliva |
| Louis Pasteur's | Confirmed existence of microbes.<br>Development of vaccines for anthrax fowl cholera & varies, also develop pasteurization & fermentation process.<br>Proved microorganisms could cause disease. |
| Robert Koch | Formulated germ theory of disease.<br>Isolated rod-shaped (bacilli) Bacteria from blood of sheep, died from anthrax.<br>Discovered bacteria that caused tuberculosis & cholera. |
| John Hog (1861) | Proposed Kingdom Protista to (accommodate microorganisms (Bacteria and euglena) |
| Ernst Hackel (1866) | Made separate kingdom Monera for prokaryotes within same kingdom Protista. |
| Herbert Copland | Elevated status of Monera to kingdom level.<br>1st time prokaryotes recognized as separate kingdom "Monera" |
| Robert H. Whittaker (1969) | Proposed five-kingdom system, of classification based in three principal modes nutrients "photosynthesis" absorption & ingestion." |
| Lynn Margulis & Karlene Schwartz (1988) | Modified five-kingdom system & assigned a separate kingdom "Monera" for all prokaryotes" |



## DOMAINS OF BACTERIA

- There is basic two domains of bacteria:

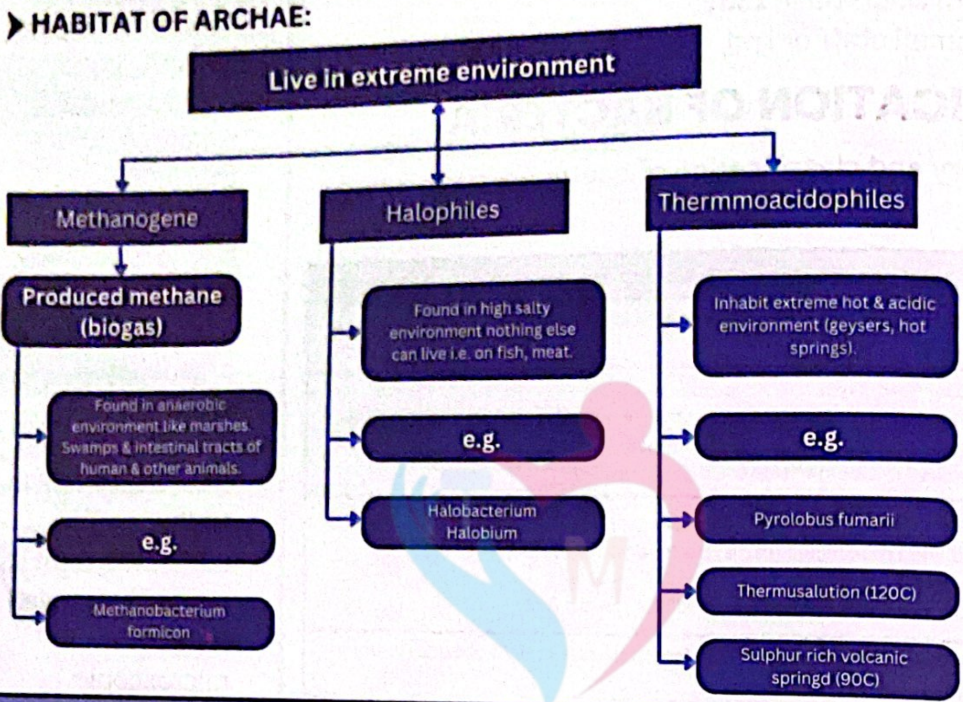
| Eubacteria | Archaeobacteria |
|---|---|
| 1. True bacteria | 1. Ancient bacteria |
| 2. Normophiles | 2. Extremophiles |
| 3. Normal PH range | 3. Acidophiles |
| 4. Normal temperature | 4. Thermophiles like Thermus acquaticus (120°C) |
| 5. Introns (non-coding parts of genes) are absent. | 5. Introns are present. |
| 6. Peptidoglycan cell wall is present.<br>7. Cell wall contains peptidoglycans<br>8. Mostly heterotrophs.<br>9. Membrane's lipids contain glycerol linked to fatty acids. | 6. Peptidoglycan cell wall is absent.<br>7. Cell wall contains proteins, glycoproteins<br>8. Mostly autotrophs.<br>9. Membrane's lipids contain glycerol linked to branched chain hydrocarbons. |

- **HABITAT OF EUBACTERIA:**

**BTB**

- **A Prokaryote** (Gk. Pro= before, Karyons=nucleus) is a unicellular organism having simple structure that lacks membrane bounded nucleus and other membrane bound organelles.
- **Ehrenberg** introduces the term **bacterium** in **1828.**
- Earlier the term bacteria was used for all the microscopic unicellular prokaryotes but later it got divided into two domains i.e.; **Bacteria and Archaea.**
- **Phylogeny** is the evolutionary relationship among various groups of organisms.
- The bacterialphylogeny was reconstructed in **1977.**
- The new phylogenic taxonomy is based on the discovery of genes encoding ribosomal RNA because there is a little or no change in rRnA generation after generation.

- Eubacteria is a huge group of prokaryotes found almost everywhere and upon which all other life form depends.
- They inhabit air, land, water, oil deposits, food, decaying organic matters, plants, man and animals.
- Contribute towards natural flora.
- Extremophiles; adapted to hot spring, alkaline/acidic soil, highly saline environment, polluted soil & water.
- **HABITAT OF ARCHAE:**




| Structure present in all bacteria | Structure not present all bacteria |
|---|---|
| 1. Cell membrane | 1. Capsule |
| 2. Cytoplasm | 2. Slime |
| 3. Ribosomes | 3. Flagella |
| 4. Chromatin | 4. Pilli & fimbriae |
| 5. Majority have cell wall except mycoplasma. | 5. Granules |

## SHAPES OF BACTERIA



- On general basis, bacteria have 3 distinct shapes:

| Cocci | Bacilli | Spiral |
|---|---|---|
| Spherical or oval shaped bacteria.<br>There are 3 types of cocci on the basis of plane of division and number of cells.<br>**One plane division:**<br>Diplococcus (two cocci)<br>Streptococci (chain of cocci)<br>**Two plane division:**<br>Tetrad (square of 4 cocci)<br>In tetrad, first vertical then again vertical but at right angle to each other.<br>**Three plane division:**<br>Cube of 8 cocci called | Straight or rod-shaped bacteria.<br>They are always found in one plan (vertical)<br>**Diplobacilli:**<br>(pair of bacilli)<br>**Streptobacilli:**(chain of bacilli) | Spiral shaped bacteria.<br>They occur usually alone but seldom in colonies.<br>They exist in one of 3 forms:<br>**Spirochete:**<br>(thin and flexible spiral) like Treponema pallidum. |

- **Thus, ribosoma[l] RNA is called molecular clo[ck] for reconstruc[ting] phylogenes.**
- Most scientist[s] view that bacte[ria] and archae probably evolve[d] from **hyperthermoph[iles]** that lived about 2.5 to 3.2 billion years ago.
- **COCCI** are spherical, non-motile, may be single or colonia[l]
- **BACILLI** are straight or rod-shaped bacteria
- They possess flagella and are motile, either singly or colonia[l]
- **SPIRAL** bacteria are corkscrew shaped bacteria flexible, motile a[nd] flagellated. they usually occur singly and seld[om] form colonies.

**BTB**

- Most bacteria possess flagella which help in gliding, twitchin[g] or change of buoyancy.
- The spirochetes have helical bo[dy] which help in anchoring.

| | | |
|---|---|---|
| Sarcina.<br>First vertical then again vertical at right angle and then horizontal.<br>**Irregular division plane:**<br>If the plan of division becomes irregular then the arrangement becomes like bunches of grapes called Styphlo-coccus.<br>**Examples:**<br>Diplococcus and streptococcus pneumoniae.<br>Staphylococcus Aureus<br>*Neisseria meningtidis* etc. | **Coccobacilli**: (bacili having spherical ends like cocci)<br>**Examples:**<br>Pseudomonas<br>Bacillus sublillis. | **Spirillum:**<br>(thick and rigid bacteria) like spirilium minim.<br>**Vibrio:**<br>(curved or comma shaped) like vibrio cholera.<br>Vibrio is intermediate between spiral and rod shaped. |

**KPK**

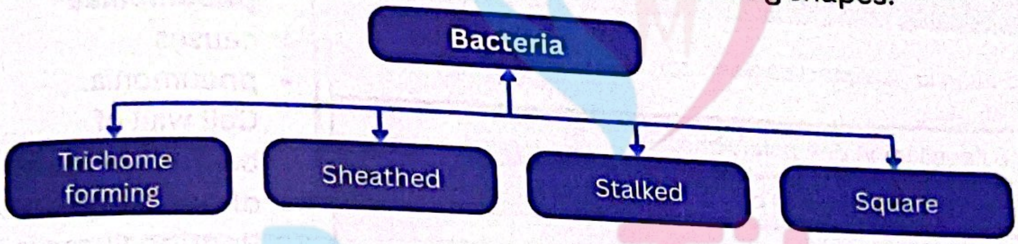
- Bacteria with capsule are called encapsulated bacteria.
- Capsule prevents dehydration of bacterial cell.
- Present beneath the extracellular substance & outer to cell membrane part of bacterial envelope.
- Composed of inner layer of peptidoglycan & outer lipoprotein membrane (found only in gram –ve bacteria.
- Absent in Mycoplasmas.
- Sugar, teichoic acid & lipoprotein, lipopolysaccharides also present linked with peptidoglycan (sugar-protein complex)
- Teichoic acid fibers protrude outside the peptidoglycan.

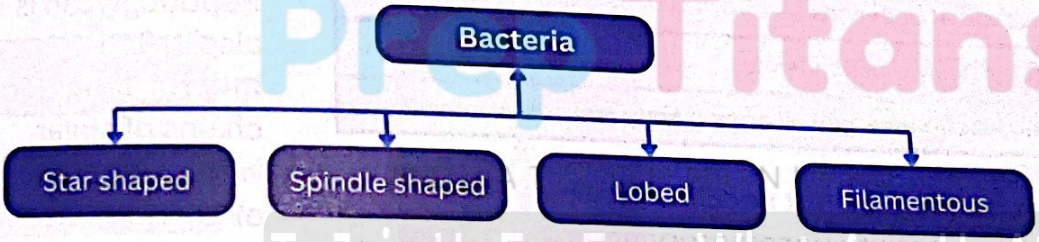
**FTB**

- Mostly bacteria have constant shapes but some are pleomorphic like Helicobacter Pylori exists in both helix and spherical shaped.

**PTB**

- Exceptions to **3 shapes**, bacteria are also of following shapes:






## SIZE OF BACTERIA

➤ Bacteria range in Size about **0.1 to 600 µm** over a single dimension.

| BACTERIA | SIZE RANGE |
|---|---|
| Mycoplasma (smallest known bacteria in spherical shape) | 100 to 200 mm (diameter) or 0.1 to 0.2 µm. |
| Escherichia coli | 2 to 6 µm or (7µm) length<br>1.1 to 1.5 µm width |
| Spirochetes | 500 µm in length |
| Staphylococci | 0.75 µm (diameter) |
| Streptococci | 1. 25 µm (diameter) |
| Epulopiscium fishelsoni:<br>(Largest bacteria can visible by naked eye)<br>Discovered in intestine of brown surgeonfish | 600 µm long<br>80 µm thick |

# BACTERIAL APPENDAGES

The structures that project from bacterial surface is called bacterial appendages. They include:

1. Flagella
2. Pilli or Fimbriae

## FLAGELLA

- Flagella are long thread-like structures used for locomotion.
- Extremely thin, hairlike appendages
- Flagella comes out from basal body through cell wall.
- They are made of Flagellin protein and lack microtubules.

Basis of classification of flagella

- Presence of flagella
- Pattern of attachment of flagella
- Number of flagella

- Flagella are classified into following groups:

| Type | Definition+example |
|---|---|
| Atrichous | No flagella (diplococcus pneumoniae) |
| Monotrichous | One flagellum at one pole(vibrio) |
| Lophotrichous | Tuft or cluster flagella at one pole(spirillum) |
| Amphitrichous | Flagella at both ends |
| Amphilophotrichous | Tuft of flagella at both ends. |
| Peritrichous | Flagella are arranged all around body (salmonella typhi) |



- Mostly bacilli and spiral have flagella, but cocci rarely have flagella.
- Primary function of flagella is motility (locomotory organ)
- Other function of flagella is chemotaxis (type of behaviour in which bacteria move in response to chemical signals)

### FTB

- Bacterial flagellum is non-contractile and lacks microtubules.
- It is about **20nm diameter** and **20um in length.**
- Bacteria consists of **three parts:**

Parts of bacteria

- Basal body
- Hook
- Filament

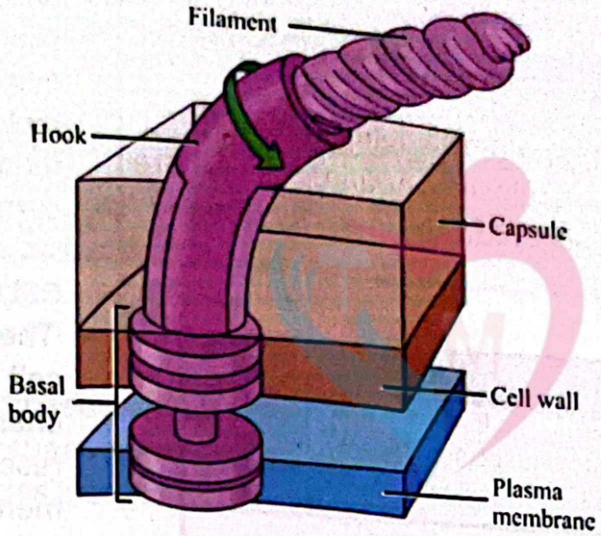
### BTB

- Some bacteria contain add... protective ou... envelope, secreted by th... cell known as slimy capsule. It is made of polysaccharide which helps in defence and adhering to ho... tissues.
- The encapsulat... bacteria cause disease while t... same bacteria without capsule do not cause disease. e.g. **Diplococcus pneumoniae** causes pneumonia.
- Cell wall of bacteria is mad... of peptidoglyca... Peptidoglycan also called **murein.** It has l... chains of sugar with short chai... of amino acids (normally **4-5 amino acids**)

### BTB

- The gram negat... is more resista... than gram-pos... against antibio... (lipopolysacch... e impedes the entry of antibiotics).

| Part | Description |
|---|---|
| Basal body | It originates from cytoplasm<br>It consists of two pairs of discs/rings (gram +ve have only one ring)<br>Discs are connected by a central rod<br>It anchors the flagellum in cell envelop.<br>It produces 360 rotatory motion and causes the cell to spin and move forward |
| Hook | Curved structure connects the basal body to filament.<br>It projected from cell surface. |
| Filament | Hollow structure originates from hook.<br>It is made of globular protein flagellin arranged in intertwined chains. |




**Motility in Bacteria**

- Flagellar Movement
  - Most bacilli & spirilli
- Spirochaetal Movement
  - In spirochaete, modified version of flagellum is Axial filament perform flexing, swimming, creeping etc.
- Gliding motility
  - Cyanobac teria
  - Myxobacteria (Don't have flagella)



## PILLI

- Hollow, non-helical filamentous appendages.
- Pilli are smaller than flagella
- True pili are present in gram –ve bacteria
- Pilli helps in conjugation.
- Pilli are made of pilin protein and can only be seen by help of electron microscope.
- Pilli are involved in attachment of bacteria to the various surfaces.
- Pilli allow bacterial cell to adhere to the tissue and the bacterial cell resists attack from immune system cells in body.
- Pilli are not involved in motility.

**BTB**

- Some bacteria contain additional protective outer envelope, secreted by the cell known as slimy capsule.
- It is made of polysaccharide which helps in defence and adhering to host tissues.
- The encapsulated bacteria cause disease while the same bacteria without capsules do not cause disease. e.g. Diplococcus pneumoniae causes pneumonia.
- Cell wall of bacteria is made of peptidoglycan.
- Peptidoglycan is also called murein. It has long chains of sugar with short chains of amino acids (normally **4-5 amino acids**)

**BTB**

- The gram negative is more resistant than gram-positive against antibiotics (lipopolysaccharid e impedes the entry of antibiotics).

## CELL ENVELOPE

- The detailed structure of bacterial structure by electron microscope revealed that bacterial envelope is the outer wrapping of the bacterial cell and it includes:
  1. Glycocalyx
  2. Cell Wall
  3. Cell Membrane
- Cell membrane is sometime considered a part of bacterial protoplasm.

## GLYCOCALYX

- Outer covering that covers outside the bacterial cell wall.
- Glycocalyx is made of polysaccharides and in some cases, protein is also present.
- Glycocalyx is involved in increment of effective diameter of bacterium which increases its immunity.
- It is also involved in the adhesion of bacteria to the living and inert surfaces and forms adherent glycocalyx-enclosed populations that are called Biofilms. Biofilm bacteria can be very hard to kill partly due to the presence of Glycocalyx material.
- Glycocalyx exists in two forms:

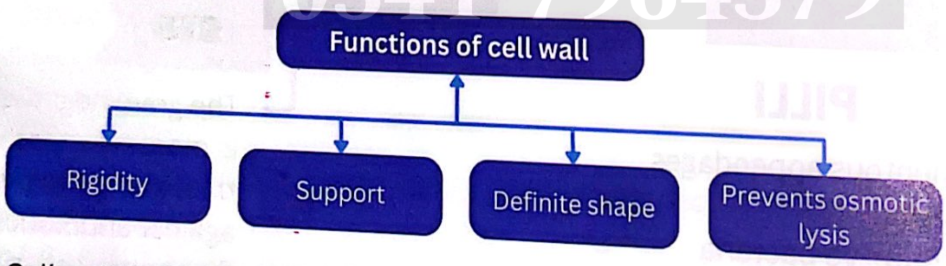
| Capsule | Slime |
|---|---|
| 1. It is tightly bound to the cell wall. | 1. It is soluble sheet of macromolecules loosely bound to cell. |
| 2. Can't be removed. | 2. Can be removed. |
| 3. It has thicker, gummy nature that gives sticky characters to the colonies. | 3. Slime is of slimy or slippery nature and gives greater pathogenicity to bacteria.It protects from phagocytosis from macrophages. |



## CELL WALL (BACTERIA)



- Cell wall is present beneath the extracellular substances and outer to cell membrane.




- Cell wall is made of Peptidoglycan (sugar-protein complex).The peptidoglycan layer provides structural support and maintain the characteristic shape of the cell.
- It is composed of an inner layer of peptidoglycan and and outer layer of lipoprotein membrane (found only in gram negative bacteria).
- Cell wall is only absent in Mycoplasmas.
- Hans Christian Gram developed a staining technique in 1884 and divided the bacteria into two groups:

**KPK**

- Cytoplasm is gelatinous ma[...] proteins, carbohydrates, lipids, nucleic a[...] salts and inorga[...] ions dissolved [...] water.
- It is thick, semi-transparent and elastic.
- The semi-fluid like portion of cytoplasm encl[...] by the cell membrane is ca[...] cytosol.

**CELL MEMBRA[...]**

- The prokaryotic cell membrane chemically resembles the membrane of eukaryotic cell [...] the exception th[...] it contains diffe[...] kinds of lipids.

**KPK**

- The genome of bacteria is diffe[...] from eukaryote[...]
- contains less D[...] It consists of a single circular chromosome a[...] few proteins as compared to lin[...] eukaryotic chromosomes.

| Character | Gram +ve | Gram -ve |
|---|---|---|
| Dye | Stained purple with crystal violet (CV-I complex) dye. They retain primary dye even when they are washed with alcohol. | Stained pink colour due to secondary dye (safranin). They lose the dye easily when rinsed with alcohol. |
| Thickness | 20-80nm | 8-11nm |
| Chemical make up | Peptidoglycan (50% dry weight) Teichoic acid. Lipoteichoic acid. | Peptidoglycan (10% dry weight) Lipoprotein. Lipopolysaccharide. |
| No.of layers | 1 | 2 |
| Lipid | Less (1-4%) | More (11-12%) |
| Outer membrane | No | Yes |
| Periplasmic space | Space between cell wall and cell membrane is present in some | Space between cell wall and cell membrane is present resent in all |
| Porin protein | Absent | Present |
| Permeability<br>Resistance to molecules | More<br>Less | Less<br>More |

### KPK

- Plasmids contains fewer genes than normal bacterial chromosome and they replicate independently.

### BTB

- Some Gram-positive produce highly resistant structure known as endospore which serves for the survival of bacteria.
- It develops within vegetative cells, so named endospore.
- The original cell forms a copy of its chromosome and covers it with hard wall, water is removed and metabolism stops.
- Endospore remain dormant but viable. The parent body disintegrates.
- At the return of favourable conditions, endospores are reactivated to normal form and restart division cycle.

### PTB

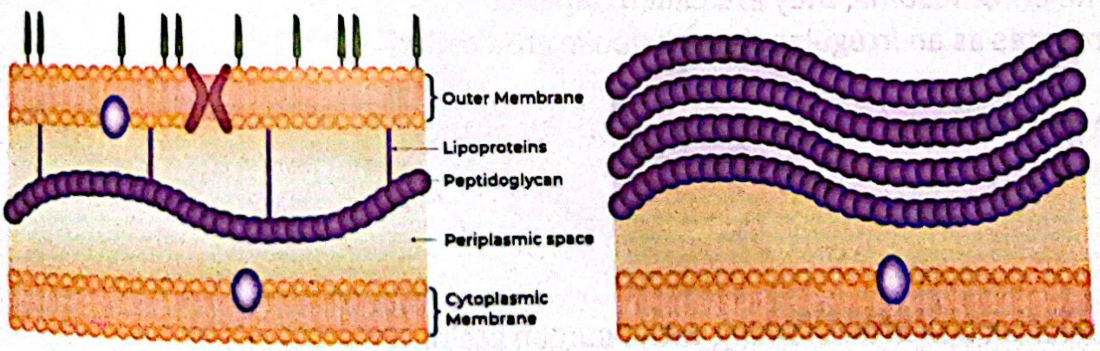
- Cell wall of archaeobacteria is different from cell wall of eubacteria
- Cell wall of archaeobacteria is made of proteins, glycoproteins and polysaccharides instead of peptidoglycan.

### FTB

- Periplasmic space in gram –ve bacteria is the site of enzymes like B-lactamases that degrade Penicillin and other B-lactam (anti-biotics)
- The Gram-negative bacteria also contain a protein Porin in the outer membrane that helps in the intake of particular molecules.
- Pilus is present in gram negative bacteria.
- They allow bacterial cell to adhere to the tissue.



| Disease | Agent | Cell wall |
|---|---|---|
| Cholera | Vibrio Cholera | Gram –ve |
| Typhoid | Salmonella typhi | Gram –ve |
| Tuberculosis | Mycobacterium tuberculosis | Gram +ve |
| Pneumonia | Streptococcus pneumoniae | Gram +ve |



## CELL MEMBRANE (BACTERIA)

- Just beneath the cell wall is cell membrane.
- Cell membrane is thin, flexible and surrounds the cytoplasm.
- It is very delicate any damage to it results in death of bacteria.
- The prokaryotic cell membrane lacks sterols like cholesterol.
- It regulates transport of nutrients, proteins, sugar, electron and other metabolites.
- It also contains enzymes for respiratory mechanism.

**FTB**

- Cell membrane of eubacteria consists of branched chain carbon and archaeobacteria consists of unbranched carbon chain.

## CYTOPLASMIC MATRIX

- Cytoplasm of prokaryotes lacks membrane bound organelles and cytoskeleton.
- It is present between cell membrane and nucleoid.
- It has gel like consistency.
- The bacterial cytoplasm is also jelly like dense mass which lacks cytoskeleton and other organelles except ribosomes.
- The plasma membrane and everything present in it is called Protoplast.
- Cytoplasmic matrix is major part of protoplast.
- Ribosome (non-membranous) is present within it.

**BTB**

- Heterotrophs directly or indirectly depe on photosynth organisms.
- Gk. **Sapro=rott**
- The chemicals released during break down of organic substa become availab other organism therefore, **sapro** are called **recyc** of nature.

## BACTERIAL GENOME

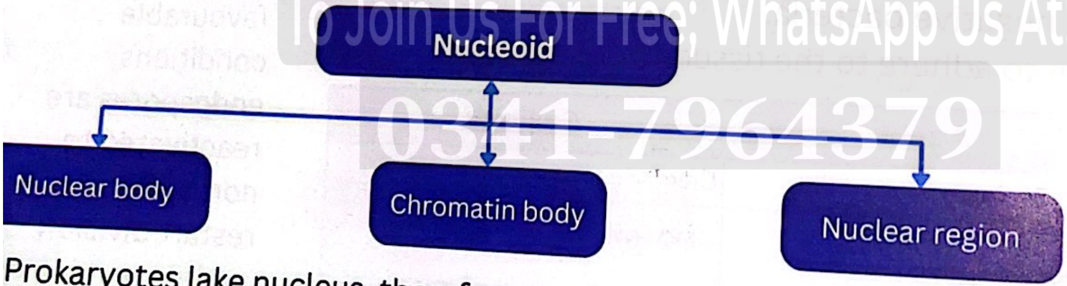
The bacterial genome consists of:

1. **Nucleoid**
2. **Plasmid**



## NUCLEOID (GENOMIC ORGANIZATION)






**BTB**

- The genome of most bacteria contains **160,0** to **12200000** b pairs.

Prokaryotes lake nucleus, therefore, nuclear material or DNA is present near the centre of cell in cytoplasm.
The material is single, circular, double stranded DNA.
As bacteria contain one chromosome, they are called haploid.
Nuclear material aggregates as an irregular shaped dense area called nucleoid.
he nuclear DNA controls the growth and metabolic activity of the ell.

**TB**

s visible in the light microscope after staining

- E. coli closed circular chromosome measures approximately 14000μm.

**FTB**

- Bacteria are haploid but a diploid phase comes in their life only during cell division when they replicate their DNA.

**KPK**

- The generation time of E. coli. is **20 minutes.** If the division goes unchecked than **36** hours would be enough to cover the face of the earth.

## PLASMIDS

- Extra-chromosomal, circular double stranded DNA molecule is called plasmid.
- They are self-replicating and are not essential for bacterial growth and metabolism.

Genes on plasmid
- Drug resistance
- Heavy metal resistant
- Insect resistant

**PTB**

- Plasmids are important vectors, in genetic engineering techniques.

## RIBOSOMES

- Ribosomes are composed of RNA and protein.
- Bacterial ribosomes are smaller in size than eukaryotic ribosome.
- Ribosomes are of 70 S.
- Its larger unit is 50 S and smaller unit is 30 S.
- They are attached to plasma membrane.
- They are protein factories.
- They are in large number, thousands in growing cells.

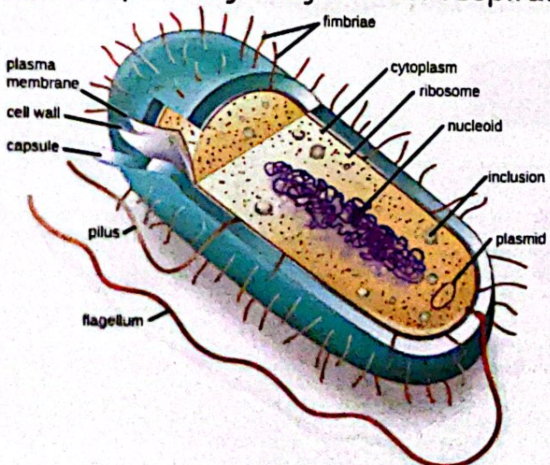


## MESOSOMES

- Mesosomes are invagination of cell membrane.
- Mesosomes are involved in DNA replication and cell division.

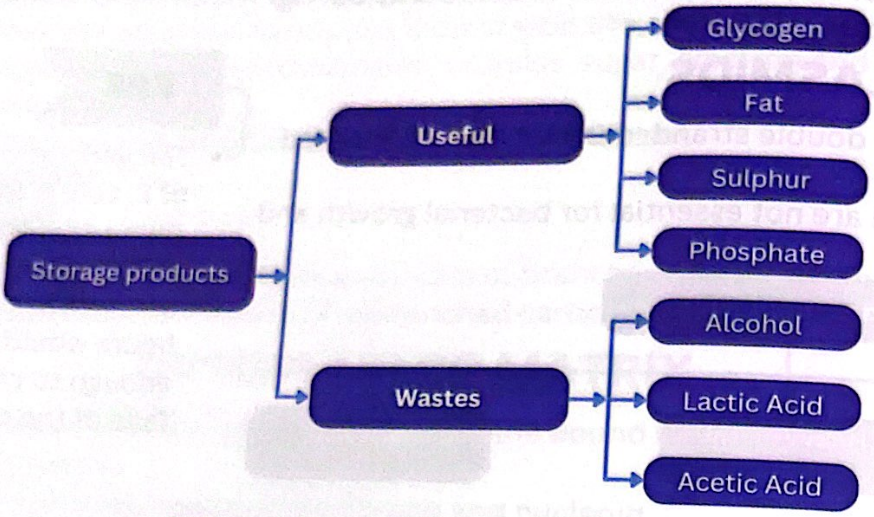
**PTB**

- Mesosomes are in the form of vesicles, tubules, or lamellae.
- Mesosomes are also involved in the export of exo-cellular enzymes.
- Mesosomes contain respiratory enzymes for respiration.



## GRANULES AND STORAGE BODIES

- Due to short supply of nutrients, bacteria are in competitive environment.
- Therefore, bacteria store extra nutrients when possible.



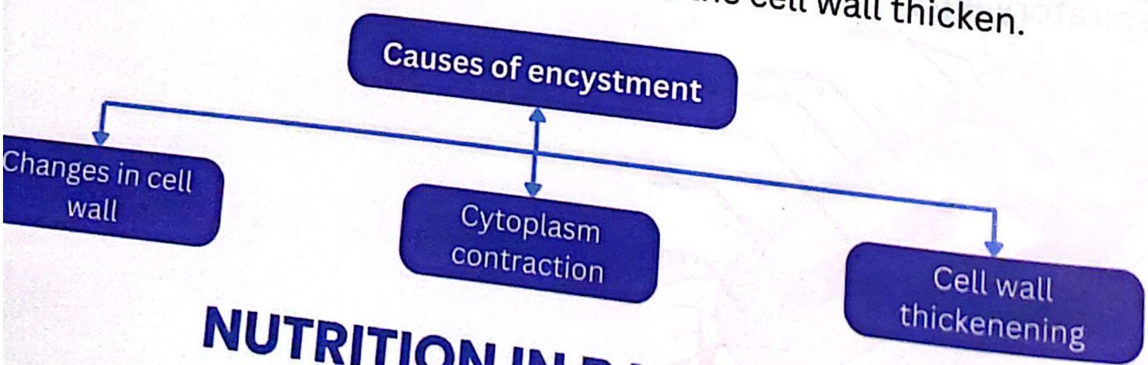

## SPORES AND CYSTS

| Spores | Cysts |
|---|---|
| 1. Spores are formed either outside the vegetative cell (exospores)or inside the cell (endospores) during unfavourable conditions.<br>2. They are metabolically dormant. | 1. Cysts are dormant, thick-walled, desiccation resistant forms. |
| 3. They are produced at late stage of cell growth. | 2. They develop during differentiation of vegetative cells. |
| 4. They are light, temperature, desiccation, heat, pH, chemical agent resistant. | 3. They are not heat resistant. |



### FTB

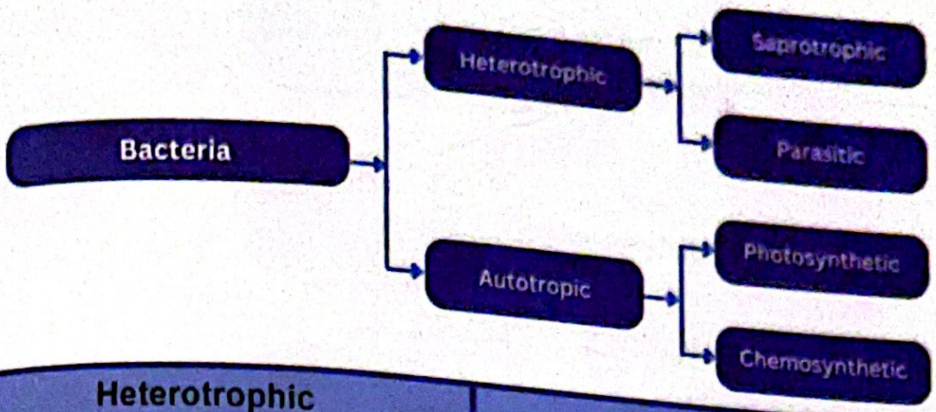
- Actinomycetes, large group of spores forming gram +ve bacteria, grow by forming long tubules called filaments.
- During nutrient poor conditions, these filaments are changed into thick-walled exospores.
- Azobacter species are cysts forming.
- Cyst formation is called encysment. Encystment occurs by changes in the cell wall, the cytoplasm contracts and the cell wall thicken.




## NUTRITION IN BACTERIA

acteria may be:

age




| Heterotrophic | Autotrophic |
|---|---|
| · Can't synthesize their food from inorganic compounds. | · Can synthesize their food from inorganic compound. |

➤ Heterotrophic bacteria may be:

| Saprotrophic or saprobes | Parasitic |
|---|---|
| · Get their food from dead organic substance (humus).<br>· Soil is full of humus.<br>· They are also called recyclers or scavengers of earth. Like azobacter, pseudomonas. | · Get their food from host and harm them.<br>· They are pathogenic bacteria like mycobacterium etc.<br>· Depend upon host. |

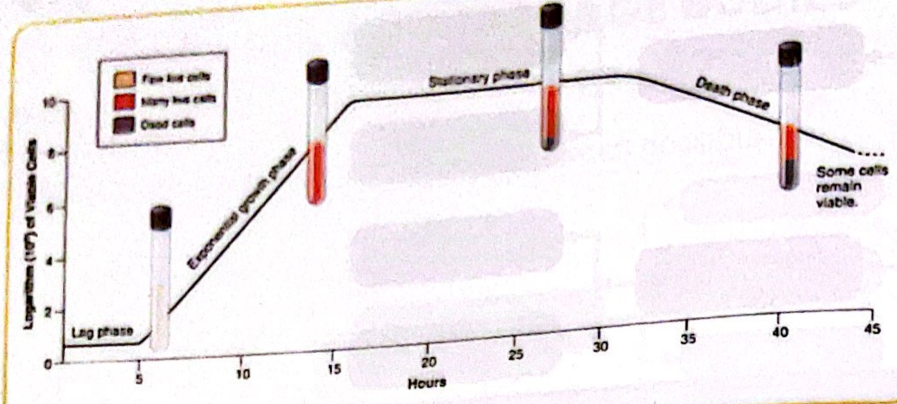
➤ Autotrophic bacteria may be:

| Photosynthetic | Chemosynthetic |
|---|---|
| · Possess chlorophyll located in mesosomes or freely dispersed.<br>· They use hydrogen sulphide instead of water as source of hydrogen and liberate sulphur instead of oxygen. | · Don't have chlorophyll.<br>· Don't use sunlight.<br>· Derive energy by the oxidation of inorganic substances such as $H_2S$, $NH_3$ etc to make carbohydrates. |
| · Purple sulphur bacteria, purple non-sulphur bacteria, green sulphur bacteria. | · Nitrifying and denitrifying bacteria etc. |



## PHASES OF GROWTH

| Phase | Description |
|---|---|
| Lag | No growth.<br>Bacteria prepare themselves for growth. |
| Log | Rapid growth.<br>Disease in human occurs during this phase of bacteria. |
| Stationary | Equal death and birth rate (constant) |
| Death | Decline phase due to exhaustion of nutrients and accumulation of wastes.<br>Death rate increases.<br>Reproduction Rate decreases. |



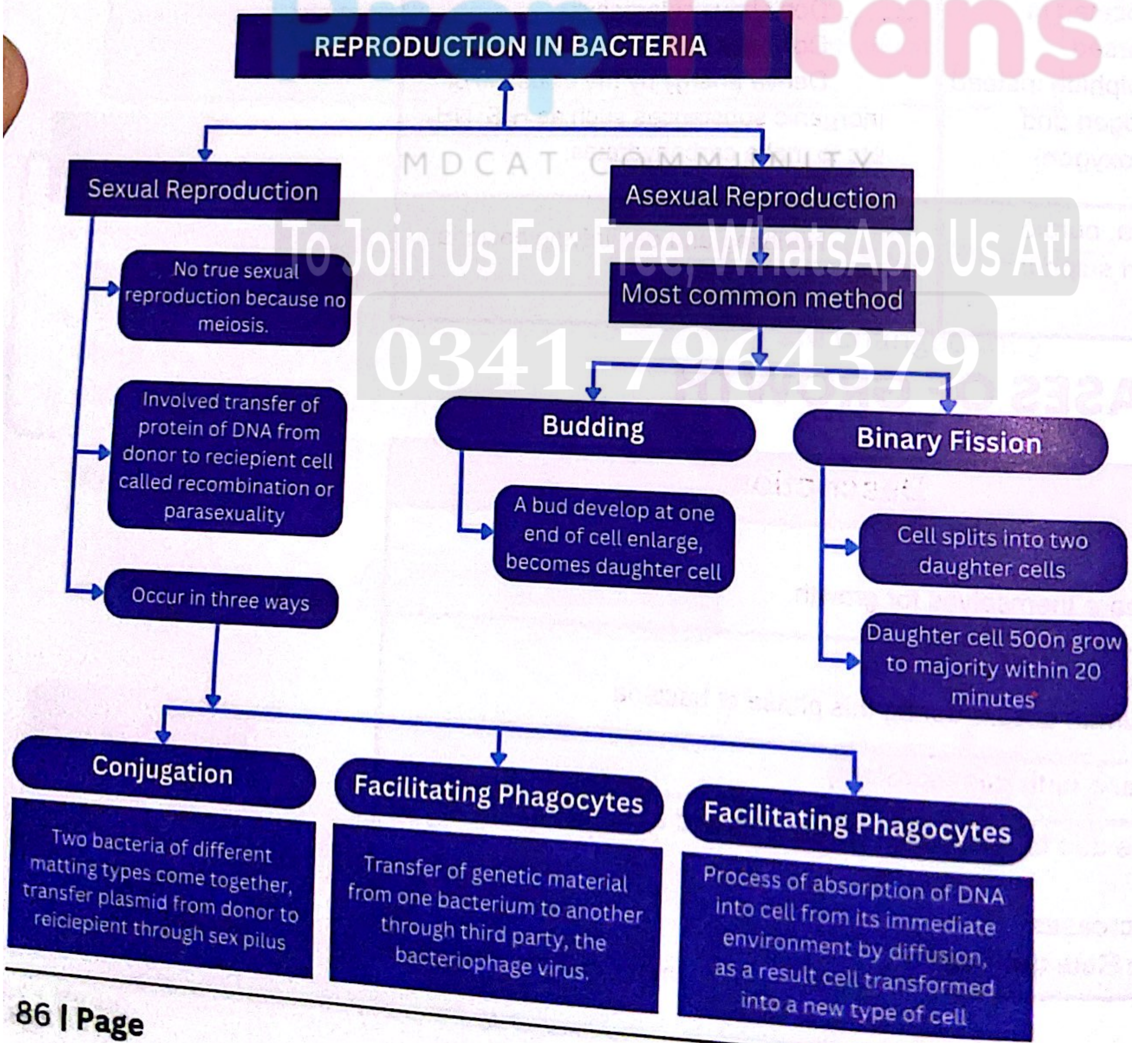

Total cells in population, live and dead, at each phase.

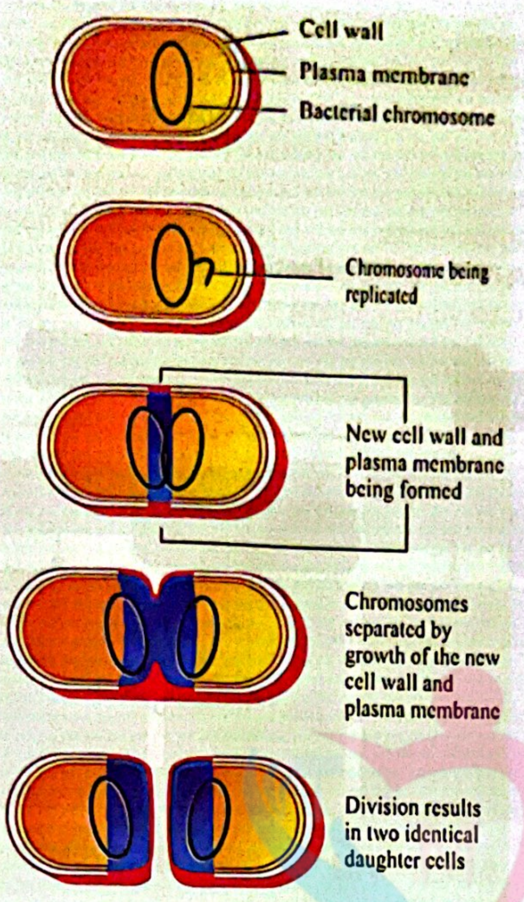
## RESPIRATION IN BACTERIA

| Type | Definition + example |
|---|---|
| 1. Aerobic | Need oxygen for breakdown of food like pseudomonas. |
| 2. Anaerobic | Don't need oxygen for food breakdown like Spirochete. |
| 3. Facultative | Grow either in the presence or absence of oxygen like E. coli. |
| 4. Microaerophilic | Need low concentration of oxygen for growth like Campylobacter. |

## REPRODUCTION IN BACTERIA

- Bacteria lack tradition sexual reproduction & mitosis, but various methods of genetic recombination misleadingly called sexual.






## ANTIBIOTICS

- Greek word (anti-against and bios life), chemotherapeutic chemical substance, used against bacteria.
- Derived from bacteria, actinomycetes & fungi, but their origin are living cells.
- Antibiotics are used against bacteria.
- They are derived from bacteria, actinomycetes, and fungi.
- Massive intake of antibiotics produces drug resistance in microorganisms like:

| Antibiotic | Misuse effects |
|---|---|
| Penicillin | Cause allergic reactions. |
| Streptomycin | Affects auditory nerve and deafness. |
| Tetracycline | Permanent discoloration of teeth in young children. |

## CONTROL OF BACTERIA

- To control diseases, we control microorganisms.
- The control of bacteria can be achieved through physical and chemical methods.
- Physical methods include steam, dry heat, gas, filtration, and radiation
- Chemical methods involve the use of antiseptics, disinfectants, and chemotherapeutic agents.

### PHYSICAL METHODS

- This method is also called sterilization process.

- Sterilization is the destruction of all life forms.
- High temperature is used in microbiological labs for control of microbes.
- Both dry and moist heat are effective.
- Moist heat causes coagulation of proteins.
- Dry heat causes oxidation of chemical components.
- Certain electromagnetic radiations below 300nm are effective.
- Gamma rays are used.

Radiation control

- Ionizing radiation
- Ultraviolet
- Microwave

- Heat sensitive compounds like antibiotics, seras, hormones, etc can be sterilized by means of membrane filters.
- Milk products can also be preserved by this method by pasteurization.
- It is used to sterilize surgical material.

## CHEMICAL METHODS

One can use the following for control:

**Antiseptics:**

- Chemicals used on living organisms.
- There are certain chemical substances (such as iodine, Dettol) that stop the growth of microbes, called antiseptics.
- Antisepsis is the procedure to stop or eliminate the possibility of infection.

**Disinfectants:**

- Used on non-living organisms.
- The important chemicals are oxidizing and reducing agents such as phenols, hydrogen peroxide, potassium permanganate, alcohol, and formaldehyde, etc.

**Chemotherapeutic agents:**

- Antibiotics work with natural defense and stop the growth of bacteria and other microbes like tetracycline, etc

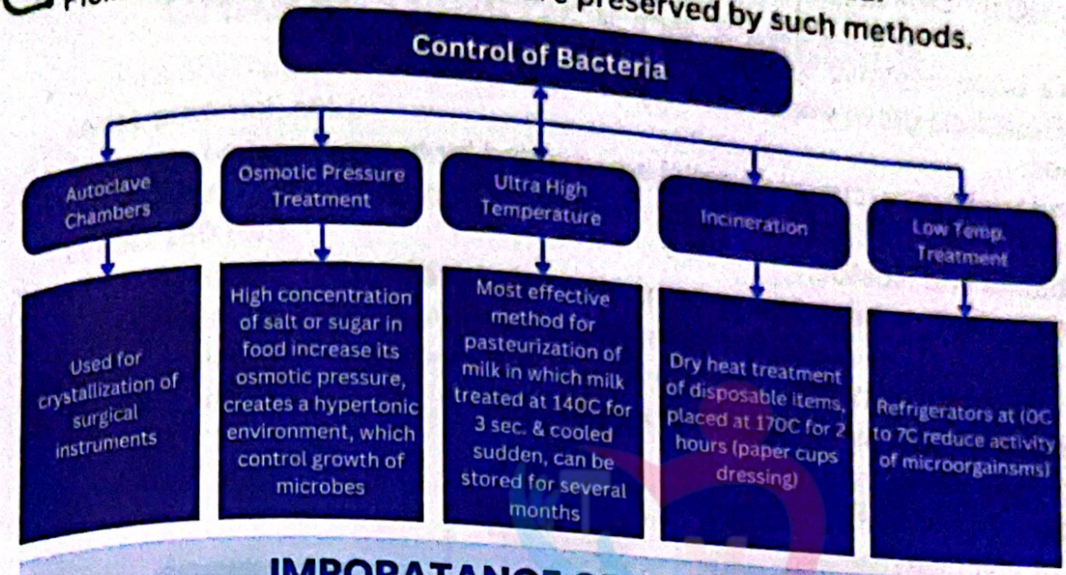
**PTB**

| Microbicidal effect | Microbistatic effect |
|---|---|
| Kills the microbes immediately. | Inhibits the reproductive capacities of cells and maintains the microbial population at constant size. |

**FTB**

- Pasteur introduced pasteurization.
- This method is used to kill microorganisms by heating at a temperature enough to kill non-spore-forming bacteria.
- Milk is pasteurized by heating at 71°C for 15 seconds and 62°C for 32

minutes.
- Food can be frozen at -10°C to -18°C for several months.
- Low temperature 10-15°C can preserve food for several days such as milk, egg, meat, cheese, and vegetables.
- Food is dehydrated so that bacteria may not grow in dry conditions.
- Acid is also added to lower the pH.
- Some chemicals like potassium metabisulphite are added.
- Pickles, candies, jam, and bread are preserved by such methods.




## IMPORATANCE OF BACTERIA

- **Ecological Importance:**
- Play a role in the decomposition of dead organic matter (recyclers of nature).
- Contribute to humus formation by decomposing dead organisms, increasing soil fertility and aiding in bioremediation. Humus also retains water, enhancing the soil's water-holding capacity.
- Rhizobium and cyanobacteria convert atmospheric $N_2$ into nitrates and nitrites, which are used by plants.
- Denitrifying bacteria play a role in denitrification.
- **Economic Importance:**
- Bacteria play a role in research, technology, and plant & animal diseases.
- Used in genetics research, such as E. coli.
- Agrobacterium tumefaciens is used in producing transgenic plants like golden rice, which prevents blindness by providing β-carotene (a precursor of vitamin A, essential for normal vision).
- In herbivorous mammals, bacteria in the gut help digest cellulose, while intestinal bacteria produce vitamins B and K.
- Used in the production of dairy products like yogurt, cheese, and butter, as well as in antibiotics, vitamins, amino acids, and enzymes.
- Can spoil food items.
- Bacteria are used in synthesizing vinegar (acetic acid), acetone, lactic acid, butanol, several vitamins, and flavoring tobacco. They also have applications in the leather and coffee industries.
- **Medical Importance:**
- Pathogenic bacteria cause diseases in humans (e.g., cholera, typhoid, pulmonary tuberculosis, pneumonia) and plants (e.g., leaf spot, blight, soft rot, wilting, and galls).





**BTB**

- Pasteurization does not change the taste of milk.

**KPK**

- Autoclave chambers are used for crystallization of surgical instruments.
- In pasteurization, milk is treated at 140°C for 3 seconds.
- Incineration is dry heat treatment
- Desiccation is the removal of water from contaminated material. So that bacteria can't grow.
- The high concentration of salt or sugar in food increase its osmotic pressure and creates a hypertonic environment which helps in controlling the growth of microbes.

- Saccharomyces cerevisiae (yeast) is used to produce the hepatitis B vaccine and alpha & gamma interferons.
- E. coli is used to produce protein products through rDNA technology, such as insulin and human growth hormone.

## CYANOBACTERIA

- Known as "blue-green algae," they are the largest and most diverse group.
- True prokaryotes with a Gram-negative type of cell wall.
- Shape varies, ranging from 1-10 μm in diameter; they are unicellular but can exist as colonies.
- Consist of filaments and trichomes (chains of cells) surrounded by a mucilage sheath.
- Examples include Anabaena and Nostoc.
- Believed to be responsible for first introducing $O_2$ into the primitive environment.
- Contain Chlorophyll a and Photosystem II.
- Carry out oxygenic photosynthesis using water and employ phycobilins as accessory pigments.
- Phycocyanin (blue) is the predominant phycobilin.
- Store food in the form of glycogen.
- Reproduce by binary fission and fragmentation.
- About one-third of cyanobacteria can fix atmospheric nitrogen.
- Nitrogen fixation occurs in heterocysts, which lack nuclei.
- Oscillatoria and some cyanobacteria serve as pollution indicators.
- Super blue-green algae, often called expensive pond scum, serve as a food source through photosynthesis. They are considered a "complete whole food," containing 60% protein with all essential amino acids in perfect balance.

mentr

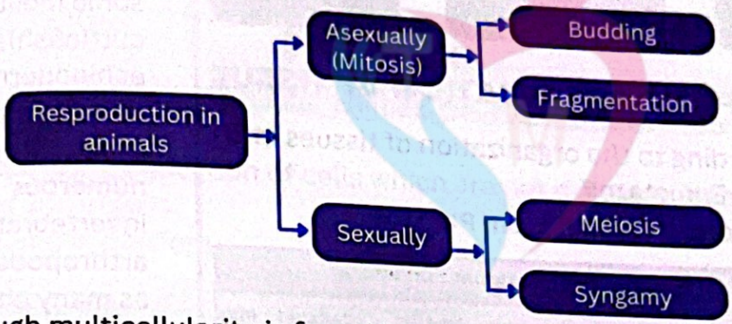
# KINGDOM ANIMALIA

## Diversity among animals

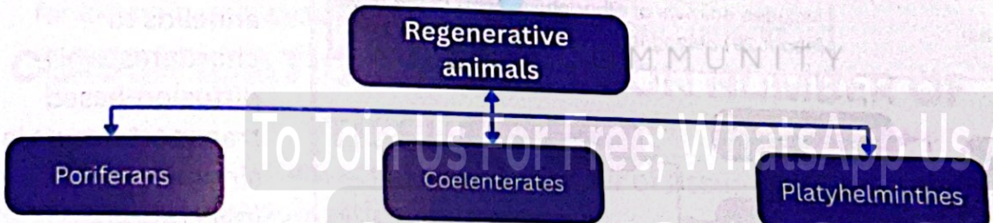
The name animalia is derived from the Latin word anima meaning soul or breath. All the animals of the world are included in the kingdom animalia

### CHARACTERISTICS OF ANIMALS

- Animals are found almost in all types of habitats (terrestrial, aquatic, aerial, arboreal, etc.).
- They may be free living motile, sessile or a parasite.
- Size ranges from microscopic (worms) to very large in size (Blue whale) almost **150 tons**.
- Kingdom Animalia consists of all animals which are eukaryotic, diploid, multicellular, ingestive heterotrophs that lack cell walls.
- They develop from two dissimilar haploid gametes, a large egg and a smaller sperm.




- Although multicellularity is found in all the kingdoms, Fungi, Plantae and Animalia but it has developed most importantly in animals- their cells are joined by complex junctions, this ensures control of communications and flow of materials between cells.




- The animals are a diverse group distinct in their form.



**PTB**

- In traditional two-kingdom systems, the multicellular animals were referred to broadly as Metazoa to distinguish them from one-celled animals, the Protozoa.
- Virtually all biologists agree that animals evolved from protoctists.

**FTB**

- Digestive system may have one opening e.g., planaria or two openings (tube-like) e.g., nematodes to mammals.
- Excretory system is absent in poriferans and coelenterates while

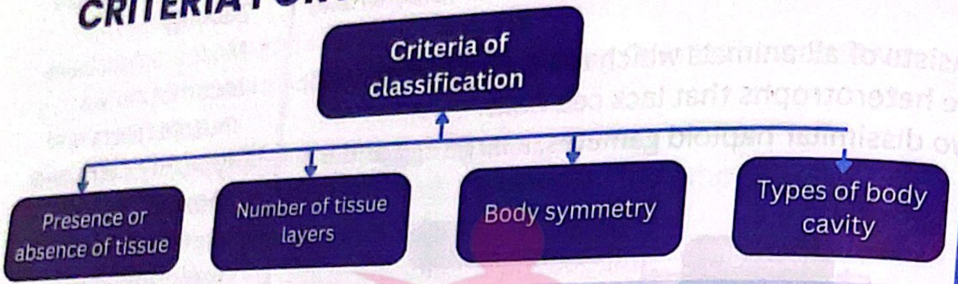
**BTB**

- Animals develop from the fusion of haploid "n" non-motile eggs and haploid "n" motile sperms. The study of animals is called **Zoology**.
- Most animals have locomotion via muscle fibers and typically carry two sets of chromosomes in their body cells.
- They respire **aerobically** and **anaerobically**, and their bodies range from soft to hard, often covered with shells, chitin, bony plates, scales, fur, or feathers.
- Animals may possess an **incomplete digestive system** (one opening) or a complete tube-like system with a mouth and an anus at opposite ends.
- The excretory system is **well developed** in most animals but absent in poriferans and coelenterates.
- Nervous systems vary: **absent** in poriferans, a **nerv net** in coelenterates, an **well-developed** i most animals

present in others.

- Nervous system is present in nematodes to chordates.
- Respiratory system is present from arthropods to chordates, while lower non chordates respire only by diffusion from surrounding water.
- Skeletal system is recorded in all animals.
- The circulatory or blood vascular system is well developed from Annelida to Chordata.
- The life cycle of animals may have larval stage like in sponges, annelids, arthropods, molluscs, echinoderms, amphibians.
- Regeneration is exhibited by sponges, some cnidarians, annelids and echinoderms.

## CRITERIA FOR ANIMAL CLASSIFICATION

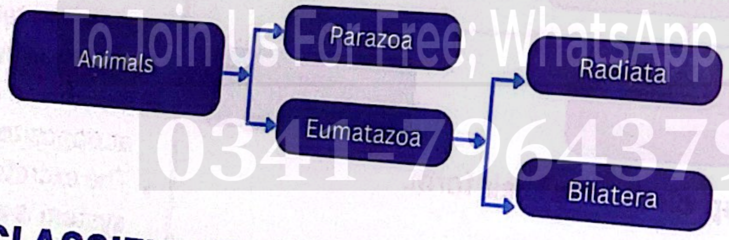



## CLASSIFICATION BASED UPON ORGANIZATION OF TISSUE

- Animals can be classified according to the organization of tissues into two subkingdoms: Parazoa and Eumetazoa.
- The simplest of the animals belong to **subkingdom Parazoa**.

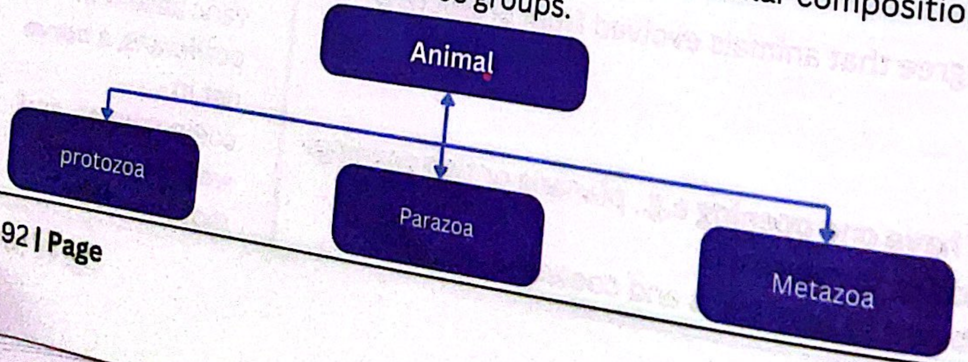
| Sub-kingdom Parazoa | Sub-kingdom Eumetazoa |
|---|---|
| These animals lack the tissues organized into organs. | These animals have tissues organized into organs and organ systems. |
| They have indeterminate shape and are asymmetrical. | They may be radially symmetrical or bilaterally symmetrical. |
| Includes phylum porifera (sponges). | Includes animals of other phyla. Most of the phyla (about 29) belong to eumetazoa. |






## CLASSIFICATION ON THE BASIS OF CELLULAR COMPOSITION

Animals have also been classified on the basis of the cellular composition of their body into the following three groups.






(with se
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systems, w
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- All animals
some form o
**skeletal sys**
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poriferans,
hydrostatic
skeleton in m
invertebrates
endoskeleton
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cuttlefish),
echinoderms,
all vertebrate
exoskeleton in
numerous
invertebrates
arthropods) a
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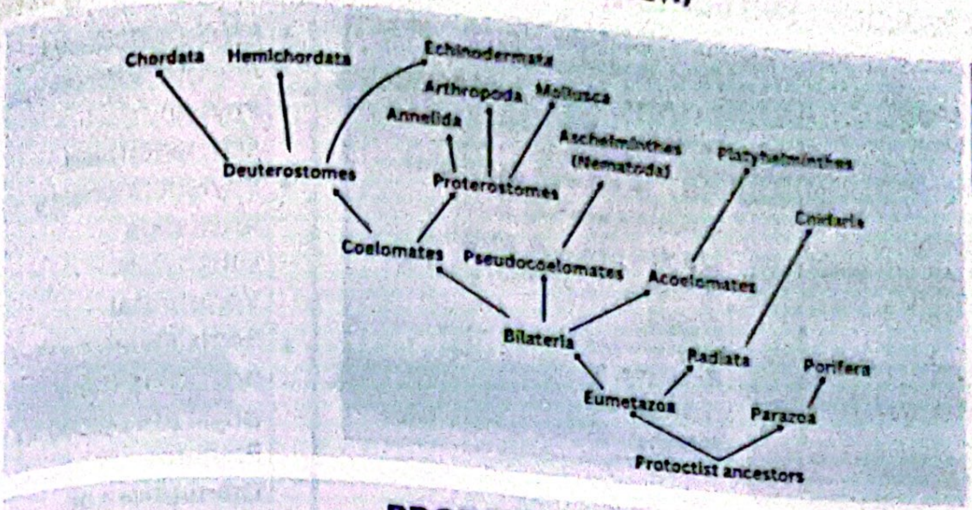
simpler
invertebrates.
- Animals reprod
**asexually** (mito
or **sexually** (me
and syngamy),
forming embry
and either bear
live young or lay
eggs.
- **Regeneration** is
seen in porifera
coelenterates, a
Platyhelminthes
- All animals lack




## PROTOZOA:

- Animals have a single celled body which performs all the vital functions of life.
- e.g., amoeba, paramecium, plasmodium, Trypanosoma etc. (In recent classification protozoa has been treated as a separate kingdom Protista).

## PARAZOA:

- These are simple multicellular animals believed to have evolved from protozoa.
- They are just a collection of cells which are not differentiated into tissues and organs.
- For example, porifera.

## METAZOA:

- Animals of this group are composed of many cells. The cells are arranged into tissues, organs and organ systems.
- This group includes all other phyla from coelenterates to chordates, for example, metazoan is kept in a subkingdom Eumetazoa

# CLASSIFICATION BASED UPON NUMBER OF TISSUE LAYERS

Animals can be classified according to number of tissue layers as **diploblastic** and **triploblastic animals**.

| Diploblastic | Triploblastic |
|---|---|
| • **The body of diploblastic animals** consists of **two germ layers** of cells, the **ectoderm** and **endoderm**. | • **The body of triploblastic animals consists of three germ layers: ectoderm, mesoderm,** and **endoderm**. |
| • Such animals have **tissue level** of organization. | • The animals have **specialized cells, organs**, and **organ systems**. |
| • There is a **jelly-like mesoglea** or **mesenchyme** between the two germ layers. | • These layers are visible **only during embryonic development** and later **transform into various organs**. |

cell walls and plastids but contain centrioles.

- Currently, about **66 thousand** vertebrate species are known, roughly **5% of the 1.3 million** total animal species.

**KPK**

- Animals in kingdom Animalia have cell membranes as their outermost cell covering, rather than a rigid cell wall.
- Animalia encompasses over **half a million species.**
- Historically, when knowledge of cells and microscopic studies were limited, scientists divided animals into two groups based on the presence or absence of a vertebral column:
- **Vertebrata**: Animals with a backbone (fishes, amphibians, reptiles, birds, mammals).
- **Invertebrata**: Animals without a backbone, further divided into these phyla:
- Phylum Porifera Phylum
- Coelenterata Phylum
- Platyhelminthes Aschelminthes
- Phylum Annelida

| | |
|---|---|
| • There are no specialized organs. A neuron net is present. | • They have a specialized nervous system, with ganglia or brain. |
| • There is only one cavity called gastrovascular cavity with only one opening. | • They have a well-developed digestive system, which is tubular, having an anterior mouth and posterior anus or cloaca. |
| • Examples are animals of phylum Cnidaria. | • Example: all phyla except coelenterata, i.e., from Platyhelminthes to chordates. |

**PTB**

- **Diploblastic animals** belong to division radiata.
- Jelly like mesenchyme or mesoglea which in most cases is non cellular.
- There is no special transport system in these animals. Most substances are distributed within their body by process of diffusion.
- These animals have radial symmetry.
- They have a sac-like digestive system with a single opening which serves for the entry of food and water and also for the removal of waste along with water.
- **Triploblastic animals** belong to division bilateria.
- Special transport systems i.e., blood vascular system is present in most of the cases.
- The digestive system is of tube type i.e., having mouth at the anterior end and the anus at the posterior end.
- Triploblastic animals may be acoelomate, pseudocoelomate or coelomate.



| Grade Radiata | Grade Bilateria |
|---|---|
| • It includes all the animals with radial symmetry having a top and bottom and similar body parts are arranged as spokes or radiate from a central body axis. | • In bilateral symmetry, a plane through the midline of the body divides it into roughly equivalent right and left halves that are mirror image. The front or anterior end of the animal generally has a head. The posterior or rear end of the animal may be equipped with a tail. |
| • No right and left side. | • There are well defined dorsal and ventral surfaces. |
| | • In Echinoderms the larval stages show bilateral symmetry, and the adult secondarily develops radial symmetry. |
| • The animals included in this grade are diploblastic. | • All the animals included in grade Bilateria are triploblastic. |
| • e.g., Jelly fish, sea anemone.<br>• Animals of phylum coelenterate are included in this group. | • e.g., from phylum Platyhelminthes to Chordata |

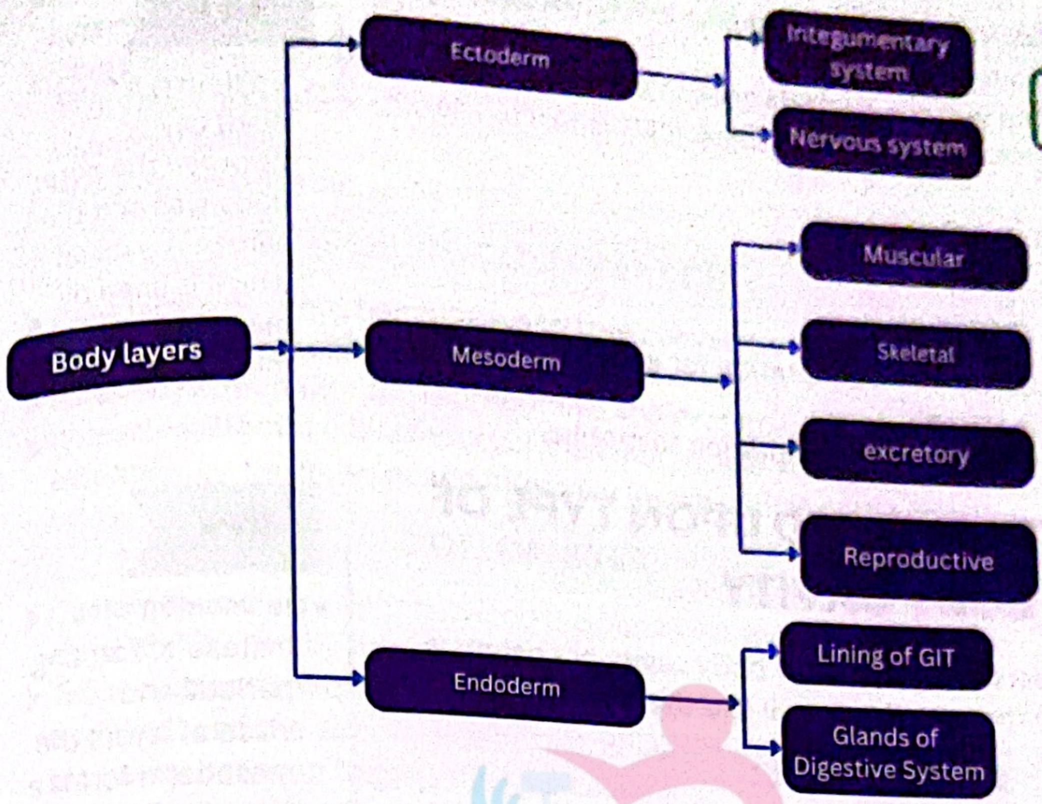
- Phylum M
- Phylum A
- Phylum
- Echinoderm
- Phylum C (excluding subphylum Vertebrata)
- Some inver not fitting phyla are p **Phylum Ctenophora**
- **minor phyla** Because the inhabit deep and are few number, the often overlo and remain understood.

**BTB**

- **Diploblastic animals** have specialized ne system rather network of ne (nerve cells) w few ganglia. (aggregation o neurons).

**KPK**

- **Diploblastic** animals produ both sexually a asexually.




**KPK**

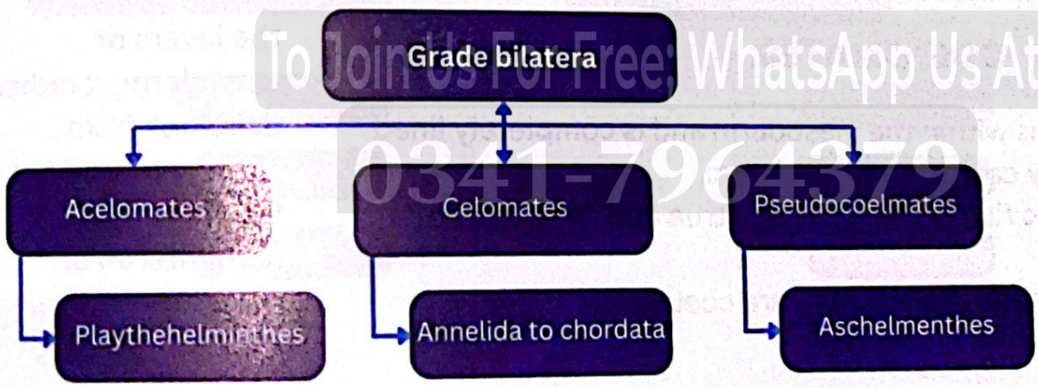
- In the majority of Bilateria the anterior end possesses a head, in which nervous tissues are concentrated and the opening of digestive tube is located.

After embryonic development, body layers in triploblastic animals are visivle as separate organs as shown above.

## CLASSIFICATION BASED UPON TYPE OF BODY SYMMETRY

Animals can be classified according to body symmetry. The subkingdoms Eumetazoa are divided into grade Radiata and grade Bilateria.

**PTB**




- **Radial symmetry** is a condition or organization in which the parts of the body are arranged around a central axis in such a way that any plane passing through the central axis divides the animal in halves that are almost mirror image of each other.
- The cylindrical body of a sea-anemone can be cut in two equal halves vertically in any plane.
- Grade Radiata includes simplest of the Eumetazoa (phylum Cnidaria)
- Most of the phyla which belong to kingdom Animalia (about 29) belong to subkingdom Eumetazoa.

- The animal (grade bilateria) can be divided into two equal parts by an imaginary line only in one plane.
- All the animals included in grade Bilateria are triploblastic. These may be acoelomate, pseudocoelomate or coelomate.

a) Radial
b) Bilateral symmetry

**FTB**

- Radial symmetry is considered an adaptation for a sessile life as it mostly contains sessile animals.
- Bilateral symmetry is considered an adaptation to motility.

## CLASSIFICATION BASED UPON TYPE OF BODY CAVITY

Animals can be grouped according to type of body cavity or coelom, a fluid filled space between the outer body wall and the digestive tube.

### ACOELOMATE:

- There is no body cavity between the digestive tract and outer body wall, so these animals are called acoelomate.
- The mesoderm is packed solidly between the ectoderm and endoderm.
- e.g., Platyhelminthes (flatworm)

### PSEUDOCOELOMATES:

- If the body cavity develops between the mesoderm and endoderm, it is called pseudocoelom (false cavity).
- Animals with this type of body cavity are called pseudocoelomates.
- e.g., Aschelminthes (nematodes).



### COELOMATES:

- If the body cavity forms within the mesoderm and is completely lined by mesoderm the body cavity is a true coelom.
- It is filled with coelomic fluid. Animals with a true coelom are called coelomate.
- e.g., Animals from annelids to chordates are coelomate.

**PTB**

### ACOELOMATES

- In phylum Platyhelminthes there is no body cavity or coelom, and the mesoderm forms a loose, cellular tissue called mesenchyme or parenchyma which fills the space between the ectoderm and endoderm.
- Mesenchyma forms a packing around the internal organs of the animals to support and protect them.

**BTB**

- Coelom is a fluid filled cavity between the outer body wall and the alimentary canal which is lined by mesodermal membranes.

**KPK**

- In acoelomates instead of forming parietal and visceral layers the mesoderm forms loose, cellular tissue which fills the space between epidermis and gastrodermis.
- Pseudocoelomat[es] are animals which although possess fluid filled body cavity, it is not a true body cavity formed between the layers of mesoderm. It rat[her] develops from blastocoel and n[ot] from the archenteron of gastrula.

- In acoelomates the gut is sac-type and there is no special transport system.
- Only excretory system is developed for the transport of excretory products. This system consists of Flame cells, excretory ducts and excretory pores.
- However, the nervous system is well developed.

## PSEUDOCOELOMATES:

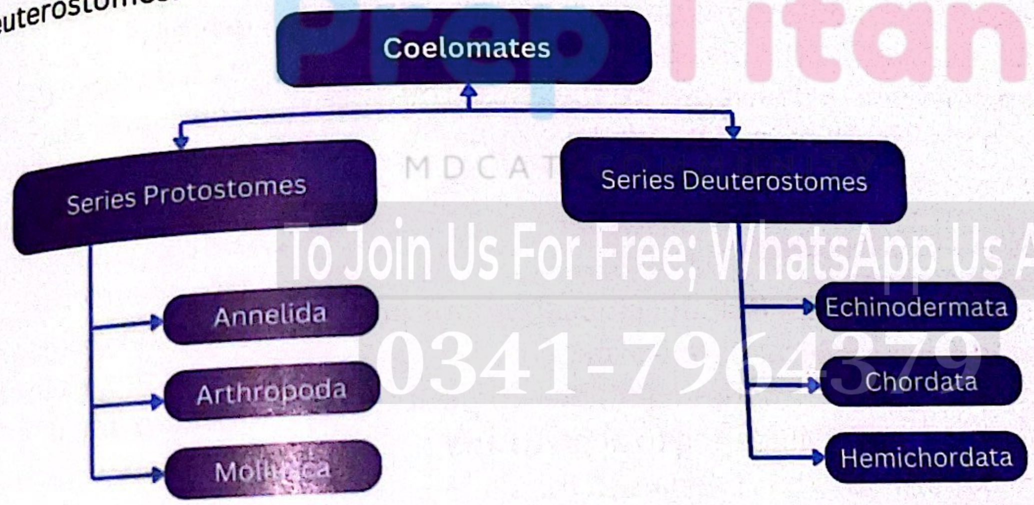
- Pseudocoelom is not homologous to true coelom because: it is not lined by coelomic epithelium.
- It has no relation with the reproductive and excretory organs.
- It develops from the blastocoel of the embryo, and it is bounded externally by the muscles and internally by the cuticle of the intestine.

## COELOMATES:

- Coelom is cavity present between the body wall and the alimentary canal and is lined by mesoderm.
- The mesoderm splits into outer parietal layer which under lines the body wall and the visceral layer which covers the alimentary canal and the cavity between them is the true coelom.
- In coelomates gut attains more complexity and neuro-sensory system is well developed along with excretory system, circulatory system, respiratory and reproductive systems.

# CLASSIFICATION OF COELOMATES

Coelomate can be divided into two groups: protostomes and deuterostomes.






**PTB**

| Series Proterostomia (Protostomes) | Series Deuterostomia: (Deuterostomes) |
|---|---|
| 1. Cleavage or division of the zygote is spiral and determinate. | 1. Cleavage is radial and indeterminate. |
| 2. During development process the mouth in these animals arises from the blastopore or from its anterior margin. | 2. During embryonic developmentmouth is formed at some distance anterior to the blastopore and blastopore forms the anus. |
| 3. Coelom or body cavity is formed due to splitting of mesoderm (schizocoelous). | 3. Coelom is developed as an outpouching of archenterons (enterocoelous). |

| | |
|---|---|
| 4. Mesoderm is derived from cells on anterior lip of blastopore. | 4. Mesoderm is derived from wall of developing gut (archenteron). |
| 5. This series proterostomia includes animals belonging to phyla aschelminthes (nematoda) annelida, mollusca and arthropoda | 5. This series includes animals belonging to phyla echinodermata, hemichordata and chordata. |

- **A spiral and determinate cleavage** is that in which the lines or planes of cleavage are not symmetrical between poles instead these are diagonal to the polar axis and produce unequal cells around the axis of polarity and all the blastomeres have determined role to play in the formations of embryo.
- The fate of each blastomere is foretold.
- **In radial and indeterminate cleavage**, the planes of cleavage are symmetrical to the polar axis and produce tiers of cells on top of each other and the fate of each blastomere is not pre-determined.
- In some anyone blastomere can produce a complete embryo.
- Patterns of embryonic development of coelom and of egg cleavage In protostomes and deuterostomes.

**FTB**

- These groups reflect two main lines of evolution based on their pattern of early development. Early during development, the embryo consists of a little ball of cells known as blastula.
- A group of cells move inward to form an opening called the blastopore. In most molluscs, annelids and arthropods, this opening develops into the mouth. These animals are **protostomes** (from Greek words meaning "first, the mouth").
- In echinoderms (for example, sea stars and sea urchins) and chordates (the phylum includes the vertebrates), the blastopore does not give rise to the mouth. Instead, it generally develops into the anus. The opening that develops into the mouth forms later in development. These animals are **deuterostomes** ("second, the mouth").

**KPK**

- **Protostomes** ("first mouth") are bilaterally symmetrical animals with three germ layers, organ-level organization, a tube-within-a-tube body plan, and a true coelom. In their embryonic development, the first opening (blastopore) becomes the mouth.
- **Deuterostomes** (e.g., echinoderms and chordates) are also coelomates but develop the anus from the blastopore first, with the mouth forming second. They exhibit:
- **Radial cleavage**, where new cells stack directly on top of existing cells
- **Indeterminate cell fate**, meaning if embryonic cells are separated, each can develop into a complete organism
- A **blastopore** that becomes the anus, while the second opening becomes the mouth.

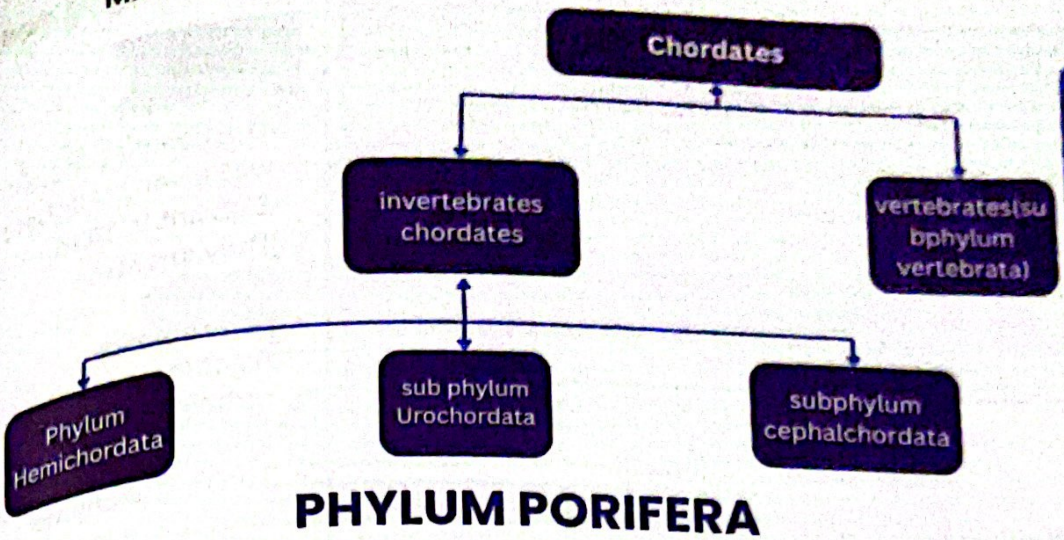


## DID YOU KNOW?

- Bioinformatics is an interdisciplinary field that develops methods and software tools for understanding biological data. As an interdisciplinary field of science, bioinformatics combines computer science, statistics, mathematics, and engineering to analyze and interpret biological data. Bioinformatics has been used for silicon analyses of biological queries using mathematical and statistical techniques.

# INVERTEBRATES

- Most animal species are those that **lack a backbone** and are commonly known as invertebrates.
- Invertebrates account for **95%** of all animal species.
- The invertebrates have been divided into **eight** major phyla:
- Porifera, Cnidarian, Platyhelminthes, Aschelminthes, Mollusca, Annelida, Arthropoda, Echinodermata.




**BTB**

**TIT BITS**

**Cleavage is the division of zygote in which the number of cells increases but the size of cell hardly increases, cleavage is either radial or spiral.**

**Do you know?**

**The blastopore is the first opening of the embryo while archenteron is the primitive gut**

# PHYLUM PORIFERA

## THE GENERAL CHARACTERISTICS

| Characteristics | Description |
|---|---|
| Porifera | Latin porus: pore. Ferra: to bear. |
| Habitat | Sponges are sessile, attached to the rocks at the bottom of water. Larvae are motile. Sponges are all aquatic, mostly marine, some found in freshwater. |
| Size | They range in size from a few millimeters wide to more than a meter long. |
| Body Organization | Body is multicellular and not organized as tissue or organs. |
| Symmetry | Body lacks symmetry. |
| Layers of Body Wall | The sponges consist of an outer dermal layer called pinacoderm, and an inner layer choanoderm made of flagellated collar cells called choanocytes. |
| Mesenchyme | The middle region is called mesenchyme. |
| Body Openings | Body is perforated by many pores called ostia. |
| Body Cavity | There is a single cavity inside the body called spongocoel. |
| Water Current System | Water enters through ostia, travels through the canal, and goes out by a large main opening called osculum. |
| Feeding | Sponges depend on food coming along with water currents. |
| Nervous System | There is no definite nervous system. |
| Skeleton | Various shapes of spicules form the skeleton. These are needle-like and may be calcareous or siliceous. The bath sponge has spongin fibre. |
| Asexual Reproduction | Asexual reproduction takes place by budding or gemmules. Buds develop into new sponges. |
| Sexual Reproduction | Sexual reproduction takes place by egg and sperm. Sexes may be separate or hermaphrodite. The embryo development includes free-swimming ciliated larval stages. |
| Regeneration | Sponges have a remarkable ability of regeneration from a small fragment. |
| Evolutionary Origin | Sponges have evolved from the protists called choanoflagellates. |
| Digestion | Digestion is completely intracellular and occurs in food vacuoles within choanocytes. |
| Respiration | Respiration is aerobic. All the cells of the dermal and gastral layers are in contact with water. There are no special organelles for respiration. |

| | |
|---|---|
| Transport System | Transportation takes place through the water current and diffusion. The water current system has greatly enlarged the area for feeding and gaseous exchange. |
| Excretion | Excretion takes place through diffusion and outgoing water current. The individual cells react as independent effectors. |
| Coordination | A sponge lacks a nervous system. Sensory cells probably seem to coordinate the flow of water. |
| Economic Importance | Skeleton of sponges is used for washing and bathing. - Sponges have great capacity to absorb water. They are used in surgical operations for absorbing fluid and blood. - Sponges are used for sound absorption in buildings. |

**FTB**

- Sponges are the only animals **with collar cells (choanocytes)**. In the sense that they apparently did not give rise to any other animal group, sponges seem to represent a **dead end in evolution**

**PTB**

- Porifera are the most primitive animals.
- Out of total **5000 species 150 species** live in fresh water while all others are marine.
- Between these two **Scolymastra joubini** - a barrel like glass sponge of layers is present gelatinous mesenchyme which may Antarctica is more than a metre tall.
- They are **macroscopic** i.e., can be seen with naked eye.
- There are no **respiratory or circulatory organs**.
- The food includes small animals, (zooplankton) and plants, (phytoplankton) which constitute about **20% of their food. 80% of their food** consists of detrital organic particles.
- Spicules are also present around osculum and ostia.
- The buds may be external or internal. The internal buds are called gemmules.
- Mostly protandrous, i.e. male sex cells develop first. In some sponges the sexes are separate. Sperms released in water are carried to the eggs by amoeboid cells.
- Fertilization occurs in mesenchyme and zygote is formed. The embryo development includes blastula and larval stages.



## EXAMPLES OF SPONGES (LESS)

- **L = Leucoselenia:** Consists of a group of erect tubes.
- **E = Euplectella:** A beautiful and delicate sponge made of a glassy framework, commonly called the "Venus's flower basket."
- **S = Sycon:** A typical marine sponge.
- **S = Spongilla:** A freshwater sponge.
- Many artificial sponges have been made from synthetic material, still the natural sponges are in demand and is an important industry in many parts of the world.
- The best commercial sponges are found in the warm waters of **Mediterranean Sea.**

**BTB**

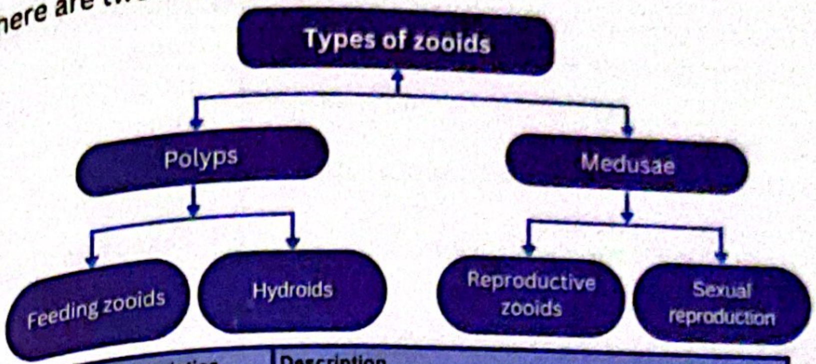
- The name Porife was given by Rob **E. Grant in 1836**
- **They are also known as**
- **Scleroblasts** Asymmetrical or radially symmetrical.
- The **mesenchym** containing many kinds of wonderi cells.
- Sponges are **heterotrophic** depend on food coming to their body with water.
- They are also use in decorative purpose and in shoe or vehicle polishing.

**KPK**

- Predatory spong have recently be discovered near lip of a mud **volcano in Barbados trench 5000 meters**
- beneath the sea. They belong to family
- **Cladorhizidae.** They are very lar about the size of
- large dog. They stab passin crustaceans with their spicules an consume them.

# PHYLUM CNIDARIA

- There are two main types of zooids:




| Characteristics | Description |
|---|---|
| Greek Word Meaning | Knide: nettle L. Aria: connected with |
| Habitat | Cnidarians are entirely aquatic, mainly marine, with a few found in freshwater, e.g., Hydra. |
| Body Forms | - Sessile species: e.g., Hydra. - Free-living and motile species: e.g., Jellyfish. - Colonial species: e.g., Obelia. |
| Cnidocytes | The name Cnidaria is given because these animals have special cells called cnidocytes. |
| Nematocysts | These cnidocytes give rise to nematocysts, the stinging cells characteristic of this group. |
| Size | They range in size from microscopic (Hydra) to two meters in length (hydrozoan polyp). |
| Symmetry | Body has radial symmetry. |
| Germ Layers | Diploblastic animals having ectoderm, endoderm, and mesoglea in between the two. |
| Digestive System | They have a sac-like internal gastrovascular cavity, which has only one opening, the mouth. The mouth is often surrounded by tentacles. |
| Nematocysts in Tentacles | Tentacles and body are provided with stinging cell organelles called nematocysts. |
| Nervous System | Nervous system consists of a nerve net and some sense organs. |
| Reproduction | - Asexual reproduction occurs by budding. - Sexual reproduction occurs by gametes. |
| Colonies | Cnidarians also occur in the form of colonies. The units of the colonies are called zooids. |



## EVOLUTIONARY ADAPTATIONS IN CNIDARIANS:

- In cnidarian, both the polyp and medusa are constructed on the same scheme. The colonial form of life shows **alternation of generation and polymorphism.**

## ALTERNATION OF GENERATION:

- Polyp reproduces asexually by budding to form medusae.
- In turn medusae reproduce sexually to form polyp. It is called alternation of generation.
- Both the generations are diploid, often the two generations consist of one free living and one attached stage. e.g. Obelia.
- In Obelia for example there is asexual as well as sexual reproduction. It has a kind of zooid known as blastostyle which gives rise to individual zooids called medusae by asexual method.

- The medusae when released in water develop reproductive organs which produce gametes that unite to form zygote from which Obelia colony is again formed.
- Some do not show any alternation of generation e.g. Hydra.
- Occurrence of different types of zooids in the same organism is called **polymorphism**.
- Some colonies grow to a great size e.g. corals.
- Gastrovascular cavity is often branched or divided with septa with a single opening. Nerve net is present.
- **Transportation** and excretion take place through diffusion.
- **There is no respiratory and excretory system**

## ECONOMIC IMPORTANCE OF CNIDARIANS :

- Coral reefs protect shores from erosion by tidal waves.
- Corals are used in jewellery and others are used in aquaria, rock gardens etc.
- Some cnidarians have poisonous stings. Large jelly fish and sea anemone are even more dangerous.
- Jellyfish is common at seashore in Karachi and stings many persons every year.

## CORAL REEFS:

- Corals are cnidarians. **It is made of $CaCO_3$.**
- **The ectodermal cells of the corals take lime from the sea water and form their exoskeleton.**
- These exoskeleton form coral reefs and even island. Coral reefs are found in the coastal water of Florida, West Indies, East coast of Africa, Australia and Island of Coral Sea.

## OBELIA

**PTB**

- **The ectoderm** forms outer covering and some cells of this layer in most **animals give rise to nematocysts**
- While the **endoderm cells** become specialized for **digestion of food**. Between the two layers is a jelly-like mesoglea.
- In these animals there is only one cavity which serves as digestive as well as body cavity which is called **gastrovascular cavity or enteron** and opens to the outside by only one opening the mouth.
- So, the animals of this group have **sac like digestive cavity**.
- In coelenterates the arrangement of body parts is in relation to centralized axis (symmetrical). An object is symmetrical where there is a correspondence in form and arrangement of parts so that a plane passing through the center divides it into similar halves.
- The coelenterates range in size from microscopic Hydro to macroscopic
- Branchioceranthus, a hydrozoan polyp that may reach two metres in length.
- Polyps are **cylindrical animals**, which in most cases are **nutritive** in function, hence named as **gastrozoids**.

**BTB**

- The nematocyst capsule with paralizing venom which acts as offensive and defensive organ
- **Exception:** Class **anthozoa** of cnidarians is triploblastic.
- In polyps mouth upward while in medusa downward
- Used as decoration in Tentacle aquarium and rock garden.
- Some Cnidarians sting human (Jelly fish and sea anemone).
- In Pakistan, they common at sea shores of Mekran and Karachi.
- Many people are affected by poisonous cnidarians while they swim.

**KPK**

- Alternation of generation is also called **metagen**

- The medusae are **umbrella like in form**. These are free swimming. The medusae are involved in sexual reproduction as they **have gonads**.
- Nematocysts are organs of **defense and offense**.
- The coelentrates are **carnivores** and feed upon small organisms which come into contact with them.
- These organisms are **immobilized** by nematocysts and taken into the digestive cavity as food where it is digested and then distributed by diffusion.
- The **nervous system** is in the form of a network of neuron cells forming an irregular net or **plexus** in the body-wall. **There is no central nervous system.**
- Many colonial coelenterates such as corals produce a hard **exoskeleton** formed of calcium carbonate ($CaCO_3$). It is secreted by epidermal cells that take lime from sea water.
- The skeleton of coral is responsible for formation of small coral islands or large **coral reefs**
- Quite a large number of cnidarians are colonial e.g. physalia, vellela etc.
- A colony is an aggregation of individuals or zooids that perform different functions for the colony
- The life cycle of coelenterates is characterized by the presence of alternation of generations. There are two generations, one Some of colonial members reproduces by sexual means and the other by asexual
- Both generations are diploid. Often the two generations consist of zooids, performing different of one free-living and one attached stage. Therefore, asexual functions for the colony e.g. generation and sexual generation alternate with one another.
- Physalia (portuguese man of war) They have **upto five different types**.

## POLYMORPHISM

- A Characteristic Feature of Coelenterates (Cnidaria)
- The occurrence of structurally and functionally more than two different types of individuals, called the zooids within the same organism is called polymorphism.
- For example, in **Obelia** there are feeding individuals, the **gastrozooids**; the individuals capable of asexual reproduction only, the **gonozooids**, **blastostyles** and free-living or sexually reproducing individuals, the **medusae**.
- The common examples of coelenterates are **"Only Happy Sea Creatures Jump"**:

| | |
|---|---|
| O=Obelia | • A marine colonial.<br>• Exhibits alternation of generations. |
| H=Hydra | • A freshwater coelenterate, exists only in polyp form, therefore alternation of generations is absent. |
| S=Sea-anemone (Actinia) | • The body consists of polyp only.<br>• Enteron is divided by large partitions called mesenteries. |
| C=Corals (Madrepora) | • The body is covered with hard calcareous skeleton formed of calcium carbonate.<br>• The skeleton forms large coral reefs and even small islands. |

| | |
|---|---|
| J= Jellyfish (Aurelia) | • The polyp is reduced, and medusa is dominant in jellyfish |

## CORAL REEFS

- *Corals are formed from the secretions produced by specialized polyps that are present in certain coelenterates.*
- *These polyps become covered by stony cups due to hardening of their secretions.*
- *From the mouth of the stony cup a polyp can pass out its tentacle for the purpose of feeding and withdraw itself where not feeding. Most such Coelenterates are colonial.*
- *The stony network or mass of such Coelenterates are called Corals.*
- *Living polyps are found on the surface layer of corals whereas underneath the mass are dead stony structures only and there are no polyps inside.*
- *The corals because of their massive structure serve as stony masses that are formed in this way are called coral reefs.*

# PHYLUM PLATYHELMINTHES (THE FLATWORMS)

## GENERAL CHARACTERISTICS

### GRADE BILATERIA

- The Platyhelminthes are triploblastic acoelomates. There is development of a third layer, the mesoderm, which separates the ectoderm and endoderm.
- The Platyhelminthes exhibit bilateral symmetry.
- The body of these animals is soft and dorsoventrally compressed.
- The body is unsegmented.

### PARASITES:

- With a few exceptions, the Platyhelminthes are parasites, mostly endoparasites, i.e., live inside their hosts.
- The most common examples are **Taenia solium** (tapeworm), **Fasciola hepatica** (liver fluke) and **Schistosoma** (blood fluke).
- Parasites are more common in tropics. Some of these cause diseases in humans.

### FREE LIVING:

- A few species are free living and found in freshwater, for example Dugesia (Planaria).

**FTB**

- **Flatworms** are **free living**, e.g., **Planaria**, or **parasite**, e.g., **Tapeworm**. They are found in **freshwater, marine, animal gut, liver**.
- **Body** is soft and flattened **dorso-ventrally**, leaf-like or paper-like.
- **Coelom** is absent, and the spaces are filled with **mesenchyme tissue**.
- **Eyespots** are present in some flatworms.

**BTB**

- Parasitic flatworms are found in the liver and gut of human beings.
- (Gk. Platy: flat, helminth: worm)

**KPK**

- They are the first triploblastic metazoan and are acoelomates.
- Their bodies are either unsegmented or superficially segmented, and true segmentation is absent.
- In free living forms the ectoderm is ciliated but in parasitic forms the cilia are absent, and a thick coat of cuticle is present for protection.
- Organs of attachment are present in the form of hooks or suckers

- Development is direct in free swimming forms and those with a single host in the life cycle.
- Free living forms are motile.

**PTB**

## RANGE:

- Their size ranges from a few millimetres (10 mm in case of Planaria) to several meters (tapeworm).

**KPK**

- Platyhelminthes is a diverse group with about 15000 species ranging in size from few millimetres (Planaria is about 10 mm) to many feet (tape worm reaches to 16 feet or about 5 meters),

## DIGESTIVE SYSTEM:

- Much of the body space is taken up by a branching sac type digestive system.
- The digestive system is poorly developed in some species or may be absent as in the tapeworms.

**FTB**

- The digestive system is incomplete i.e., gastrovascular type, having only one opening to the exterior, the mouth.

**BTB**

- Free living forms possess an incomplete digestive system i.e., with a single opening known as mouth while less developed or absent in parasitic forms.

**KPK**

- Digestive system in free living form is developed but in parasitic forms it is either poorly developed (Class Trematoda) or completely absent (Class Cestoda).
- Tape worm absorbs digested food from the wall of the intestine of the host where they remain attached with the help of scolex (head) which is provided with hooks and suckers.

## EXCRETORY SYSTEM:

- The excretory system consists of branching tubes ending in bulb-like cells, the flame cells.
- Excretory system is well developed.

**FTB**

- Excretory system consists of two lateral canals with branches bearing flame cells (protonephridia).

**KPK**

- The excretory system is with few flame cells (flame cell is a structure with thin elastic walls with a nucleus and cavity containing many long cilia flickering like a flame) attached with ducts which open at excretory pore.



## NERVOUS SYSTEM

- A well-developed nervous system is present in Platyhelminthes.
- It is in the form of either a simple network of nerves or ganglia.
- The sense organs are present at the anterior end.

**FTB**

- The nervous system consists of a pair of anterior ganglia with longitudinal nerve cord.

## RESPIRATORY & CICULATORY SYSTEM

- They are Absent.

## PARASITIC MODE

The parasitic species absorb nutrients from the hosts. The free-living species (Planaria) feed on small animals and bodies of dead and decaying animals.

## LOCOMOTION

The free-living forms are motile. They move by cilia present on their undersides (Planaria). In parasitic forms the movement is restricted.

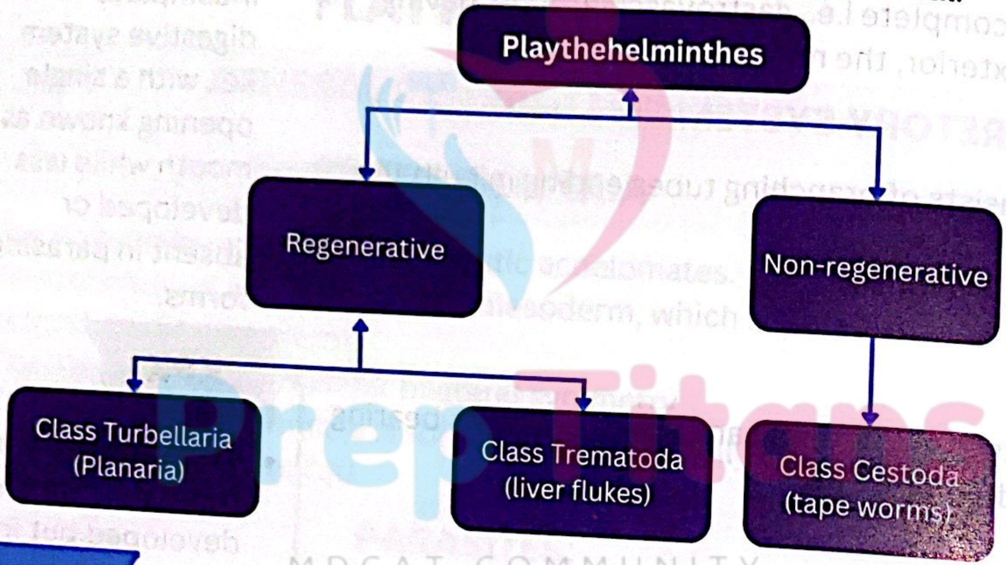
## REPRODUCTION

The Platyhelminthes reproduce both by sexual and asexual means of reproduction. Asexual is by means of fission.

**FTB**

- Most forms are monoecious.

The reproductive system is complex, usually with well-developed gonads, ducts and accessory organs. The fertilization is internal.






**BTB**

- Asexual by fission (regeneration) sexual reproduction is also present. These worms are bisexual with well-developed gonads, ducts and accessory organs, fertilization is internal, development may be direct or indirect.

**PTB**

- Asexual reproduction is by fission in which the animal constricts in the middle into two pieces, each of which regenerates the missing part. The sexually reproducing species are hermaphrodite, i.e., both male and female reproductive organs are present in the same individual.

## LARVAL FORM

- Sometimes present.

# COMMON EXAMPLES OF FLAT WORMS

- (mnemonic: Don't Forget To Study)

**BTB**

- The nervous ... consists of a network of n... with two longitudinal ... and an anter... cerebral gang...

**KPK**

- The nervous s... is with a pair ... anterior cereb... ganglia and a ... ventral gangli... connected by ... ring and one ... three nerve c...

**BTB**

- Respiration an... transport occ... diffusion.

**KPK**

- Muscular laye... well develope... free living for... which help in locomotion.

**KPK**

- Eggs are small ... yolk and are produced in ve... large numbers.
- Self and cross ... types of fertili... is present amo... Platyhelminthe...
- Fertilization is always interna...
- The fertilized e... are passed out which either ...

| | |
|---|---|
| D=Dugesia (Planaria) | • A free-living flatworm with a ciliated outer surface |
| F=Fasciola (Liver fluke) | • It is an endoparasite in sheep and occasionally in humans<br>• It has **suckers** used for attachment to host tissue.<br>• It completes life cycle in **two hosts**, a snail, sheep, or man<br>• It lives in the **bile duct** of its host<br>It infects liver |
| T=Taenia (Tape worm) | • An endoparasite of humans, cattle, and pig that completes its<br>• life cycle in **two hosts.**<br>• **It infects human intestine.**<br>• The intermediate host is **pig or cattle.**<br>• The body is ribbon-like and divided into segments<br>• called **proglottids** which contain mainly sex organs.<br>• The segments continue to break off and are passed out<br>• from the intestine along with feces |
| S=Schistosoma (Blood fluke) | • It is a **blood parasite.**<br>• It infects cattle. |

new individual as in planaria and tape worm or different type of larvae are formed as in liver fluke.

- All the members of this phylum are solitary i.e., not found in colonies.

# ADAPTATIONS FOR PARASITIC MODE OF LIFE

The parasitic **Platyhelminthes** have completely adapted themselves to **parasitic mode of life** by the development of the following characteristics:

1. The **epidermis** is absent, and there is the formation of a resistant **cuticle** for **protection**.
2. They have developed **adhesive organs**, such as **suckers** and **hooks**, for **attachment** to the host.
3. There is degeneration of the **muscular system** and **nervous system**.
4. The **digestive system** has become simplified due to increased **dependence** on the host.
5. The **reproductive systems** are **complicated**, and the **ova** are produced in **huge** numbers to ensure **continuity** of the species.
6. The **complexity of life cycle** and presence of **more than one host** during the life cycle is also an important **parasitic adaptation**.



**FTB**

## IMPORTANCE OF PLATYHELMINTHES

- The parasitic forms of flukes and tapeworms are very harmful for man, e.g., tapeworm infect human intestine, liver fluke infect liver, the blood fluke effect cattle etc.

**PTB**

### INFESTATION

- In **Taenia** (tape worm), the development of the **zygote** begins while it is still inside the **uterus** of the female.
- The last **segments** or **proglottids** and their **uteri** contain completely developed embryo.
- The fully mature proglottids break off from the body and pass out of the body of man along with faeces (undigested waste).

**KPK**

- **Economically, they are very important.**
- **Liver flukes** and **tape worms** cause serious diseases in **sheep, goat, cow, buffalo, pigs, horse, donkey,** and other **domesticated animals,** causing heavy mortality and great economic losses.
- Human tapeworm (Taenia saginata) is a serious health hazard in poor and developing countries of Asia and Africa.
- Its infection results in:
- **Retarded growth**
- **Nausea**
- **Weight loss**
- **Abdominal pain**
- **Nervous disorders** (resembling **epilepsy**)
In children, it may also cause **death**

- The **embryo** inside the egg is round and has **six chitinous hooks**. It shows limited **movement** of contraction.
- To develop further, it must reach a **second host**, which may be a cow.
- The parasite remains embedded in the **voluntary muscles** of the cow.
- If an **improperly cooked beef** is eaten by a person, the **parasite** that has not been killed begins to develop further in the **intestine** of man.

## DISINFESTATION

- Once the **parasite** has entered the **intestine** of man, it is difficult to **remove it completely**.
- Care should be taken to **cook beef properly** before eating it, so there is no chance of the parasite entering the **digestive system**.
- If it has entered, certain **medicines** are taken to **remove it**.
- Its **complete removal** is necessary because if only the **head** remains inside the intestine, it can **grow into a new tapeworm** once again.
- Besides **treatment with drugs**, physicians also give **enema** to the patient to fully **remove the parasite**.

# PHYLUM ASCHELMINTHES

- The phylum is also known as Nematoda (Greek nematos : thread).

## GENERAL CHARACTERISTICS OF PHYLUM ASCHELMINTHES (ROUNDWORMS)

| Characteristics | Description |
|---|---|
| Habitat | • The roundworms are free-living or parasitic, and live in soil, roots, human and animal intestines, and muscles. |
| Size | • Most roundworms are less than five cm long, and many are microscopic, but some parasitic roundworms grow more than one meter in length. |
| Symmetry & Germ Layers | • The worms have bilateral symmetry, with three germ layers. |
| Body Shape | • The body is cylindrical, tapering at both ends. |
| Digestive System | • The digestive tract is complete.<br>• It is a straight tube with mouth and anus at opposite ends (tube within tube arrangement). - Pharynx is muscular and well-developed. |
| Muscular System | • The muscular layer is not continuous. - It is divided into four longitudinal quadrants: two dorsolateral, two ventrolateral. |
| Body Cavity | • The body cavity is a pseudocoelom. |
| Excretory System | • Consists of a pair of longitudinal excretory canals and an excretory pore.<br>• Also includes protonephridia. |
| Nervous System | • The nervous system consists of a nerve ring around the oesophagus (pharynx).<br>• Nerve cord and fibers extend in various directions. Longitudinal nerve cords are connected by transverse nerves. |
| Reproduction | • Fertilization is internal.<br>• Most animals are unisexual. |

**BTB**

- Greek: Askos Sac, Helmint means worm
- **Guinea worm**
- **Gaenorhabd** (free living)
- **Ascarislumb s** is a human intestinal pa it also migrat the lungs an causes cough other compli

**KPK**

- Males are sm than females
- Power of Regeneration absent.
- In male the t a long, coiled thread with a seminal vesic

| | |
|---|---|
| **Circulatory & Respiratory System** | • Circulatory and respiratory organs are absent. |
| **Evolutionary Adaptations** | • Aschelminthes have adapted to almost every habitat available to animal life.<br>• Their pseudocoelomate body plan, cuticle, hydrostatic skeleton, and longitudinal muscles allow them to adapt to various environments.<br>• They have exploited virtually all potential hosts. |

## EXAMPLES AND ECONOMIC IMPORTANCE – PARASITIC DISEASES

- Aschelminthes is important from the point of view of its parasites which has a great variety causing some very serious diseases in man and plants.
- **Mnemonic for examples: AREA**

| | |
|---|---|
| **A = Ascaris lumbricoides** | It is an **intestinal parasite** of man (small intestine).<br>Can also migrate to lungs and cause cough.<br>**Diseases caused by Ascaris:**<br>• Anaemia<br>• Abdominal pain<br>• Fever |
| **R = Rhabditis** | Contains numerous species normally found in soil, organic matter, or water and faeces of man or animals. |
| **E = Enterobius vermicularis** | Commonly known as **pinworm.**<br>Cosmopolitan but more common in Europe and America.<br>Pinworms are **parasites** in the human caecum, colon, and appendix.<br>**Their movement causes:**<br>• Intense itching of anus<br>• Inflammation of the mucous membrane of the colon and appendix, resulting in insomnia and loss of appetite. |
| **A = Ancylostoma duodenale** | Commonly known as **hookworm.**<br>A parasite of the human small intestine in Asia, North Africa, and Europe.<br>Very dangerous because it holds the villi of the intestine, sucks blood, and body fluids.<br>Produces an **anticoagulant** during feeding to prevent blood clotting, leaving the wound bleeding.<br>In children, it can cause:<br>• Anaemia<br>• Retarded physical and mental growth. |
| **Free Roundworms** | Found in soil.<br>Cause diseases to potato, onion, cotton, and apple. |



**FTB**

- Most nematodes are **dioecious**.
- All types of life cycle occur from the simple and direct to the complex with intermediate hosts from normal **dioecious reproduction to parthenogenesis**, hermaphroditism and alternation of free living and parasitic generation.
- Aschelminthes have extraordinary capacity to survive conditions suboptimal for viability.

which posteriorly opens in to rectum by a short ejaculatory duct.

- Female reproductive organs are a pair of very much coiled ovaries passing into uterus and two uteri unite posteriorly forming vagina which on the **ventral surface** at the female genital aperture situated in the middle line.
- The **most common animal of this phylum** is Ascaris lumbricoides, Endoparasite in the small intestine of man.
- It lives freely in the lumen (cavity of the small intestine).
- The body is elongated, cylindrical and tapering on both ends.
- The anterior part of both male and female is similar that is pointed but the posterior part of the male ascaris is curved with two spinelike structures called **penial setae**.
- In female the posterior end is not sharply pointed.
- Ascaris Enterobius vermicularis mostly parasitizes children which ingest its egg.
- These parasitic forms cause great economic losses in

**PTB**

- Triploblastic Animals – Pseudocoelomates Aschelminthes (Phylum Nematoda) - The Round worms.
- The name Nematoda means "**pointed ends**".
- One end of the body is anterior; however, the head is not clearly marked and there are no special sense organs at this end.
- The nematodes exhibit bilateral symmetry and the body is **unsegmented**.
- Pseudocoelom is derived from the hollow space, the **blastocoel**, situated in the blastula, an early stage in embryological development, and **not from the mesoderm**.
- It consists of a number of **vacuolated cells** filled with a **protein-rich** fluid which develops high hydrostatic pressure.
- In parasitic nematodes the digestive system is simple. A fluid filled space is present between the body wall and alimentary canal.
- The excretory system consists of two longitudinally running excretory canals which unite at the anterior end to form a single canal that opens to the exterior through an **excretory pore on the ventral surface**.
- There is a nerve ring around the pharynx, which give rise **to dorsal, ventral and lateral nerve cords** running throughout the length of the worms.
- The **sense organs** are in the form of sensory papillae present on the lips **at the anterior end**.
- The **gaseous exchange** takes place through **general body surface**.
- **Locomotion** is by undulating waves of contraction and relaxation of muscles. These muscles are arranged in four bands, two dorso-lateral and two ventro- lateral.
- The circular muscles are absent; therefore, the bending is dorsal **ventral only**.
- The **sexes** are separate. The female gonads are ovaries and these produce eggs. These male gonads are testes which produce sperms.
- A larval stage is present in the life cycle.
- Round worms are everywhere outdoors, where they play an important role in breaking down organic matter.
- A rotting apple may contain **90,000 worms**.
- **Billions** thrive in each acre of topsail.



## PHYLUM ANNELIDA

- The annelids are called **segmented worms.**

### THE GENERAL CHARACTERISTICS

| Characteristics | Description |
|---|---|
| Annelida | • (Latin Annelus = little ring) |
| Habitat | • They are free-living (Earthworm) or ectoparasitic (e.g., Stylaria, Hirudo).<br>• Found in soil, freshwater, and marine environments (e.g., Nereis). |
| Body Segmentation | • Body is metamerically segmented, meaning ... segments both internally ... |

terms of ... expenditure ... crop des...
- Free living ... nematodes ... decompose ... matter and ... major role in ... **fertilization** ... Nematodes ... important ... most food ... and food ... therefore ... economically important.

**BTB**

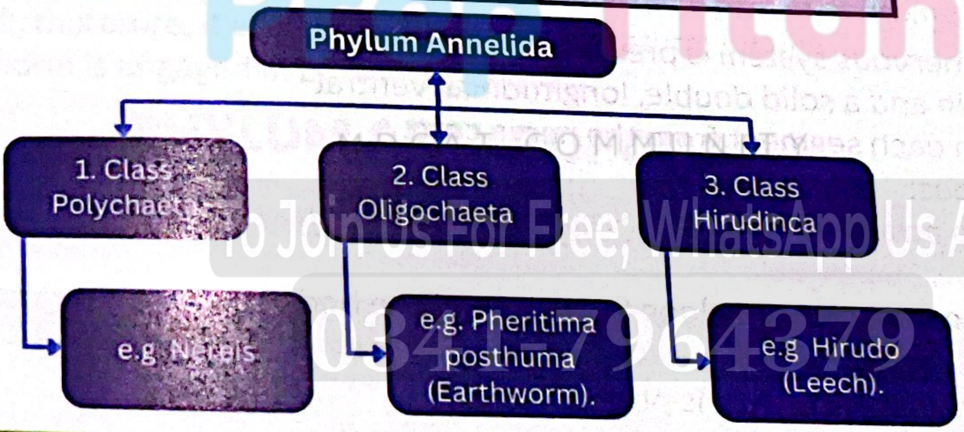
- Most animals ... bisexual or monoecious ... leeches, earthworm) ... are unisexual ... dioecious (ne...
- Many worms ... used as food ... fishes.

**KPK**

- Annelids are the **First true Coelomates**.
- The word Anne... is of Greek ori...
- In earthworm **... to five pairs of hearts called pseudo-hearts** present, which contract rhythmically to keep the blood moving in the system.
- Colour of the ... is red due to ...

| | |
|---|---|
| **Organ Systems** | • Circulatory, nervous, and digestive systems extend throughout the body. |
| **Coelom** | • True coelom.<br>• Separated into compartments.<br>• Coelomic fluid serves as a hydrostatic skeleton and helps in movement. |
| **Digestive System** | • Digestive system is in the form of an alimentary canal<br>• Divided into distinct parts, each performing a specific function<br>• Mouth and anus are present.<br>• The mouth is surrounded by a lobed structure, the prostomium.<br>• Digestive system is poorly developed in parasitic species |
| **Circulatory System** | • Annelids are the first group in the animal kingdom to have a definite closed blood vascular system. |
| **Excretion** | • Excretion takes place by nephridia, which are ciliated organs present in each segment of the body. |
| **Nervous System** | • Central nervous system is present.<br>• Consists of a pair of dorsal ganglia and a solid double longitudinal ventral nerve cord.<br>• Nerves arise in each segment from the nerve cord. |
| **Respiration** | • No specialized respiratory system.<br>• Respiration occurs through the moist skin. |
| **Locomotion** | • Body wall contains circular and longitudinal muscles, which help in locomotion.<br>• Locomotion occurs via interaction of muscles and hydrostatic skeleton.<br>• Organs of locomotion in annelids include chitinous chaetae (setae), embedded in sacs in earthworms.<br>• Parapodia is present in the body wall of Nereis.<br>• Chaetae are absent in leeches. |
| **Reproduction** | • Sexual reproduction is the most common mode.<br>• Most annelids are hermaphrodites (e.g., Earthworm, Leech).<br>• Sexes are separate in some annelids (e.g., Nereis).<br>• Fertilization is external.<br>• Development is direct or indirect through trochophore larvae. |
| **Regeneration** | • Regeneration is common in annelids. |

- **Nephridium opens to the exterior through nephridiopore.**
- **The body is covered with glandular epidermis, which secretes mucus and keeps the skin moist.**
- **Respiration is through general surface but some annelids e.g. neries have gills under parapodia. The body is covered with cuticle.**
- **Animals of this group are an integral part of the food chains both in aquatic and terrestrial environment.**






**FTB**

## ECONOMIC IMPORTANCE OF ANNELIDS

- **Polychaetes** play a significant role in marine ecosystems as they serve as food for fish, contribute to the formation of calcareous tubes, and aid in reef formation.
- **Earthworms** are beneficial for soil health, as they contribute to soil improvement and act as a natural plough, enhancing soil aeration and fertility.
- **Leeches**, on the other hand, are primarily known as ectoparasites;

they can parasitize both humans and cattle, impacting their health.

## EVOLUTIONARY ADAPTATIONS IN ANNELIDS

- A basic adaptive feature in evolution of annelids is their septal arrangement resulting in fluid filled coelomic compartments.
- Fluid pressure in those compartments is used as a hydrostatic skeleton for movement.
- Powerful circular and longitudinal muscles have been adapted for flexing shortening and lengthening of the body.
- There is a wide variation in feeding adaptations from the sucking pharynx of the oligochaetes and the chitinous jaws of carnivorous polychaetes to the specialized tentacles and cirri of the ciliary feeders.
- In Polychaetes the parapodia have been adapted in many ways and for many functions, chiefly locomotion and respiration.

**PTB**

- Triploblastic Animals - Coelomates
- The body becomes divided transversely into a number of similar parts or segments. The subdivisions may be indicated externally by constrictions of the body surface. Internally, the segments are separated from each other by septa extending across the coelom.
- The animals are triploblastic and coelomate, showing **bilateral symmetry.**
- The annelids include worms, which may be **marine (nereis), freshwater (stylaria) or found in damp soil (earthworms).**
- **Some are parasites, for example, Hirudo - (leech).**
- Annelids have true coelom i.e. the mesoderm splits into parietal layer which lines the body wall, and the visceral layer which covers the alimentary canal.
- A well-developed central nervous system is present in annelids. It comprises of a simple brain and a solid double, longitudinal, ventral nerve cord. Nerves arise in each segment from the nerve cord.
- The muscles are of two types:
- Circular Muscles: These are arranged along the circumference of the body.
- Longitudinal Muscles: These are arranged along the length of the body. the body cavity.
- **Earthworm** Burrowing activity of earthworms permits greater penetration of air into the soil and improves drainage capacity of the soil.
- It also enables roots to grow downwards through the soil more easily. Mixing and churning of the soil is brought about when earth which contains inorganic particles is brought up to the surface from lower regions.
- Earthworm is perhaps most active segmented worm in churning the soil, therefore it is commonly termed as **natural plough.**

## CLASSES OF ANNELIDA

| Features | Class Polychaeta | Class Oligochaeta | Class Hirudinea |
|---|---|---|---|
| Head region | Distinct | Not distinct | Not distinct |
| Sexes | Separate | Hermaphrodite (bisexual) | Hermaphrodite |
| Organs of locomotion | Parapodia | Setae | No organs. Move by contraction of their body and with the help of suckers. |
| Habitat | Mostly aquatic (marine) | Terrestrial or aquatic | Aquatic |
| Trocho-phore larva formation | Yes occurs | Don't occur | Yes occurs |
| Other features | Eyes and structure known as palps and tentacles present. | These animals have internal and external segmentation. | Their body has a fixed number of segments. Each segment has additional circular rings or markings called annuli |
| Examples | • Nereis<br>• Aphrodite (sea mouse)<br>• Chuetopterus (parchment tube worm)<br>• Terebella | • Lumbricus terrestris (earthworm)<br>• Pheretima posthuma (earthworm)<br>• Dero<br>• Tubifex | Hirudo medicinalis (medicinal leech)<br>Polygordius |

## ADDITIONAL POINTS

- **Leeches** are **ectoparasites** for man and cattle.
- Leeches have **chitinous jaws** for making a puncture in the skin of the host. They also have an **anticoagulant secretion**.
- **Earthworm** is perhaps the **most active segmented worm** in churning the soil; therefore, it is commonly termed as natural plough.
- Earthworm is engaged in **burrowing activity**.

# PHYLUM ARTHROPODA

## GENERAL CHARACTERISTICS



| Characteristics | Description |
|---|---|
| Phylum Size | The phylum contains more species than any other phylum. They are commonly called Arthropods (arthron = joint + pods = feet). |
| Body Segmentation | The body is segmented. Each segment is attached to its neighbor by a modified portion of cuticle which is thin and flexible. They possess jointed appendages modified for specialized functions. |
| Common Origin | Believed to have a common origin with annelids due to shared characteristics like segmented body, appendages, and cuticle. |
| Habitat | Arthropods have adapted to every type of habitat on land and in water. |
| Body Covering | The body is covered with a waterproof chitinous cuticle secreted by the epidermis. |
| Body Parts | Head, Thorax and Abdomen |
| Coelom | The coelom is not the main body cavity. Instead, a haemocoel is developed, which communicates with the blood vascular system. |

**KPK**

- Arthropoda is the **most successful group** and the **largest phylum** of the animals.
- They have **jointed limbs** and generally **every segment of the body has a pai[r] of legs** (also called limbs or appendages).

| | |
|---|---|
| Digestive System | The digestive system is in the form of an alimentary canal with two openings, the mouth and anus. It is divided into different parts for specialized functions. Food consists of small plants and animals. |
| Excretory System | A well-developed excretory system with Malpighian tubules is present. Nitrogenous waste is excreted as solid uric acid. |
| Nervous System | A highly developed nervous system is present, consisting of paired ganglia (simple brain) connected to a ventral double nerve cord. A ganglion is present in each segment, with nerves arising from them. Sensory organs include compound eyes and antennae. |
| Respiration | Most arthropods use an extensive tracheal system formed of air tubes called tracheae for gas exchange.<br>Aquatic arthropods respire through gills and book lungs. |
| Circulatory System | The blood circulatory system is open. Blood is colorless as it lacks hemoglobin. |
| Skeleton | Arthropods have an external skeleton (exoskeleton) in the form of an outer cuticle, which is lightweight and primarily made of chitin. It provides an attachment surface for muscles aiding in locomotion. |
| Locomotion | Arthropods exhibit active and swift movements. They swim, crawl, or fly, depending on their habitat. |
| Organs of Locomotion | Locomotion is facilitated by paired appendages and, in some cases, paired wings. |
| Reproduction | Sexes are separate. Testes and ovaries produce sperms and eggs, respectively. |

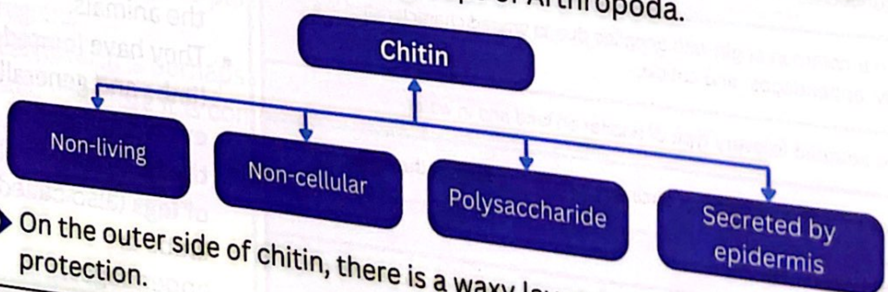
## METAMORPHOSIS

- Life history of insects is characterized by metamorphosis (meta = change + morphe = form).
- This is an **abrupt change** of form or structure during the life cycle.
- There are **three morphologically distinct stages** in the life cycle, the egg "finally "develops into larva which is converted into motionless pupa that finally develops into an adult.
- In some primitive insects the metamorphosis is incomplete. The larva resembles adult and is called **nymph or instar**.
- It lives in the same habitat as an adult.



## GENERAL ORGANIZATION OF ARTHROPODS

- Arthropods have characteristics of higher forms such as **bilateral symmetry, triploblastic, coelomic cavity and organ systems and have reached the peak of invertebrate evolution.**
- Two of their main achievements are the chitinous exoskeleton and locomotory mechanism. These animals can walk, Swim and fly.
- The jointed appendages (limbs) have been modified or diversified for various uses in the different sub-groups of Arthropoda.




- On the outer side of chitin, there is a waxy layer. In general, it is for protection.

- Blood is called **haemolymph** because (it does not carry oxygen) it only carries food to different tissues of the body.
- Arachinids, a group of arthropods including scorpion, spider etc. respire through special structures, arranged side by side like books in a bookshelf, hence called **book lungs**.
- Excretion takes place either through Malpighian tubules (as in insects) or green gland or coxal gland (as in crustacean).
- Some insects like honeybees, ants, termites etc. show **social behavior**.
- They live in colonies and divide their work among different groups.
- A ganglion is present in each segment and nerves arising from these ganglia connect the whole body.
- The responses are well coordinated. Sensory organs are eyes and antennae.

- But it also serves as lever for the movement of muscles of jointed limbs.
- In the young Arthropods such as insect larvae, chitinous exoskeleton is shed from time to time to allow the growth of the larva. This process of shedding of exoskeleton is called **moulting or ecdysis**.
- In short, the exoskeleton of chitin in the Arthropods is one of the primary factors in the success of Arthropoda as it helps them to adapt to a wide variety of habitat.

## ORIGIN OF ARTHROPODS

- It is believed that Arthropods share a common origin with annelids.

**Common features of annelids and arthropods**
- Appendages
- Cuticle
- Segmented body

**PTB**

- **Insects** (cockroaches, grasshoppers, butterflies, mosquitoes) are **most common arthropods** on the earth.
- The aquatic species include both freshwater and marine. Many of these can fly, therefore visit air periodically.
- Arthropods are **variable structurally**. Some are worm-like centipedes while the others are flying insects
- Most arthropods possess an **extensive tracheal system** formed of air tubes called tracheae for the exchange of gases. Main tubes open to the exterior through paired openings, called **spiracles**.
- The blood flows in the body cavity bathing the tissues of the body. However, there is a **primitive heart, and a main Blood vessel situated dorsally.**

## SIMILARITIES OF ARTHROPODS AND ANNELIDS

§ Arthropods share with annelids the characteristic of having the body divided into similar segments. In Arthropoda, however, **segmentation is not metameric**, organs are not repeated in the different segments. Each somite typically is provided with a pair of jointed appendages.

§ But this arrangement is often modified with both segments and appendages specialized for different functions in different habitats.

§ However, in all kinds of habitat the jointed appendages provide an efficient means of locomotion, offence, and defense and also help in reproduction.

## CLASSIFICATION OF ARTHROPODS

Phylum Arthropoda is a large group consisting of great variety among them. Some of its important classes are as follows

**BTB**

- The name of this phylum was given by Ernst Von Siebold **1845**.
- The biggest phylum comprised about **75% of the animal kingdom**.
- Sensory receptors especially eyes are present and cuticular hairs. The mechanoreceptors e.g., antenna
- Guanine is also their nitrogenous waste, removed thorough unique excretory organs called as Malpighian tubes or green glands.
- Hemocyanin (a copper containing protein) is present in their blood.
- Reproduces sexually and all are unisexual.
- Fertilization is internal and external.
- Excretory organs are paired with excretory glands known as coxal, antennae or maxillary glands. In many forms Malpighian tubules act as excretory organs.
- Central nervous system has dorsal brain connected by ring around the oesophagus with double

**Classification of arthropods**

- Crustaceans
- Insecta
- Arachnida
- Myriapoda

## CLASS CRUSTACEA

- These **arthropods are aquatic** and have **gills** for respiration. On the dorsal side of the **cephalothorax** the exoskeleton is in the **form of carapace.**
- In the exoskeleton deposition of salts in addition to chitin makes **it firmer.**

**Functions of appendages**

- Capturing food
- Walking
- Swimming
- Respiration
- Reproduction

- Coelom is reduced and is in the form of Hemocoel. Head has two pairs of Antennal appendages, one pair of mandibles (jaws) and two pairs of maxillae.
- Sexes are mostly separate.
- **e.g.**, Daphnia, Cyclops, Crabs, lobsters, prawn, wood louse Etc.

## CLASS INSECTA

- This is **the largest group not only of Arthropoda but of all the animal kingdom and has great variety.**
- Insects are found everywhere, many show social behaviour. The body in, insects has three distinct regions head, thorax and abdomen.
- There are a **pair of antennae and compound eyes on the head**. The head is usually vertical to the body and jaws are ventrally placed. The thorax has three segments in which are present three pairs of jointed legs and in many one or two pairs of wings. Abdomen has varying number of segments.
- Brain is formed of fused ganglia and double nerve cord is ventral.
- Sexes are separate and **animals are oviparous.**
- Metamorphosis takes place during development.
- **e.g.**,dragonly mosquito, butterlies, moths, wasps, and beetles etc.



## CLASS ARACHNIDA

- Body has the **anterior segments that are fused to form a combined cephalothorax, with a pair of appendages called chelicerae with claws, two pairs as pedipalps and four pairs of legs.**
- There are **no antennae and no true jaws**. Abdomen may be segmented or unsegmented with or without appendages.
- Respiration is by gills or special structures called book lungs, excretion is by the Malpighian tubules.
- Eyes simple, sexes are separate. They are **oviparous (lay eggs).**
- **No true metamorphosis.**
- Most **spiders have eight eyes placed** in such a way as to give them panoramic view of the predators and prey.

ganglionated ventral nerve cor
Compound eyes and some other receptors (ocelli) are also recorded

**BTB**

### BENEFITS

**CRUSTACEANS**

Provide food direct and indirectly to human (such as prawn, crab, Lobster etc. Some are harmful because act as intermediate host for human parasite (larvae of nematodes) is carried by Cyclops, the guinea worm.

**BENEFICIAL INSECT**

Help in **pollination** (such as ants, butterfly, bees). Us as food in some par of world (such as grasshopper, cricke Destroy **useless weeds** by feeding upon them. Eat other harmful insects such as dragon fly feed on mosquitoes.

**SCIENTIFIC USE**

Several insects are being used for scientific studies, such as cockroach fruit fly, grasshopp etc.

**HARMS**

- **Damage crops,** fr trees and timber trees: For

- Main insects
  - Scorpions
  - Spiders
  - Mites
  - Ticks

## CLASS MYRIAPODA

- The body is divided into large number of segments each having a pair of legs.

- Myriapoda
  - Head
    - Pair of antenna
    - Pair of eyes
  - Examples
    - Centipedes
    - Millipedes

**FTB**

- Body is **flexible** at many places to allow **articulation**.
- The male and female arthropods are often unlike. The **reproductive organs and ducts are paired**. The testes produce sperms and ovaries produce eggs.
- Fertilization is mostly **internal**.

- Respiratory system
  - Aquatic
    - Gills
  - Terrestrial
    - Book lungs
    - Trachea

Circulatory system consists of **dorsal contractile heart** (blood sinuses).

## METAMORPHOSIS IN ARTHROPODS

- Development takes place through metamorphosis. It is of two types.
- In **incomplete metamorphosis**, only the larval stage is present, which resembles the adult, called nymph (e.g., cockroach, chinch bug).
- In **complete metamorphosis**, the life cycle consists of egg, larva, pupa, and adult (e.g., butterfly, housefly). In the larvae (e.g., insects), the chitinous exoskeleton is shed from time to time to allow growth of the larvae.
- This process of shedding the exoskeleton is called moulting or ecdysis.

## SCIENCE TIDBITS

- Processing of organic materials by earthworms into homogeneous and humus- like material is called vermicomposting.
- This material is a complex mixture of fecal matter of earthworms and microorganisms.
- In vermicomposting system, earthworms act as voracious feeder, modifying composition of organic waste, gradually reducing its organic carbon and C:N ratio and retains more nutrients (nitrogen,K,P,Ca)

example, grasshoppers, bugs, locusts, beetles, caterpillars, weevils, aphids etc.

- **Damage books** (silver fish), household articles (such as white ants destroy furniture). They irritate humans in various ways, such as bees sting, causes many eye diseases. There are certain blood sucking insects e.g., Louse.

### ARACHNIDA

Poisonous arachnids like scorpions, certain spiders sting humans. Ticks and mites are parasitic disease carriers. Mites destroy crops. Beneficial arachnids like scorpions and spiders feed on injurious insects.

- Apiculture is the scientific method of rearing honeybees. "It is the care and management of honeybees for the production of honey and the wax.
- In this method of apiculture, bees are bred commercially in apiaries, an area where a lot of beehives can be placed.
- Apiaries can be set up in areas where there are sufficient flowering plants.
- Sericulture, or silk farming, is the cultivation of silkworms to produce silk.
- Although there are several commercial species of silkworms,
- Bombyxmori (the caterpillar of the domestic silkmoth) is the most widely used and intensively studied silkworm.
- **Members of Onychophora**, a group of arthropods, are believed to be separated from the main evolutionary line of the arthropods.
- They share characteristics with both annelids and arthropods, hence believed to be the most primitive arthropods and are considered a connecting link between Annelids and Arthropods.
- This class contains only about 70 species classified in 10 genera.

## WHY ARTHROPODS ARE SUCCESSFUL AMONG ANIMALS?

- They possess jointed feet, segmented body, which provides them great mobility.
- Chitinous exoskeleton protects the body and makes it light. Internal fertilization and development within egg case.
- Appendages perform various functions such as quick movement, defense and offense and help them to live in a variety of habitats.



## ECONOMIC IMPORTANCE OF ARTHROPODS

- Man, and insects have been at war for the same food, same place to live in.
- Insects attack man, his domestic animals and also his crops, causing a number of diseases.
- They are not only a health hazard but also cause economic loss to man by destroying his property and crops.
- Some insects are also useful to him such as the honeybee or the silkworm. Insects are therefore of great importance to mankind.

### HARMFUL INSECTS

- Many types of mosquitoes, lies, leas, lice and bugs **transmit disease** causing organisms to man and domestic animals.
- We are familiar with mosquito of genus Anopheles, the female of which transmits Plasmodium that **causes malaria** in man.
- The **Tse-tse fly** of African countries **transmits Trypanosoma**, the cause of sleeping sickness and skin diseases.
- The **common house fly** carries disease causing organisms to contaminate food and cause cholera, hepatitis etc.
- Some species of Trypanosoma cause diseases in cattle.
- A number of insects lay eggs on fruits and other commercial crops such as sugarcane, maize, cotton and also on vegetables etc. The larvae of these insects **damage fruits and the**

**PHYLUM MOLLUSC**

**BTB**

- Soft Bodied Animals.
- The term mollusk was introduced by Kontson in **1650**
- Squid is largest invertebrate **15 meters(50 feet)**

economic loss to farmers.

- The locusts that move in large numbers from country-to-country cause damage to standing crops and other plants.

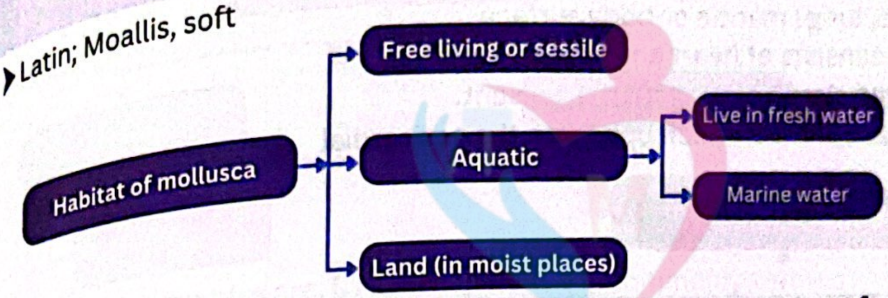
## BENEFICIAL INSECTS

- The useful insects are the honeybee that provides man with **honey and also wax.**
- Similarly, the **silkworm gives us silk**. There are some insects that are predaceous on other harmful insects.
- Some insects are **scavengers**, and they eat up dead animals and vegetable matter.
- Insect larvae are a **source of food for fish.**

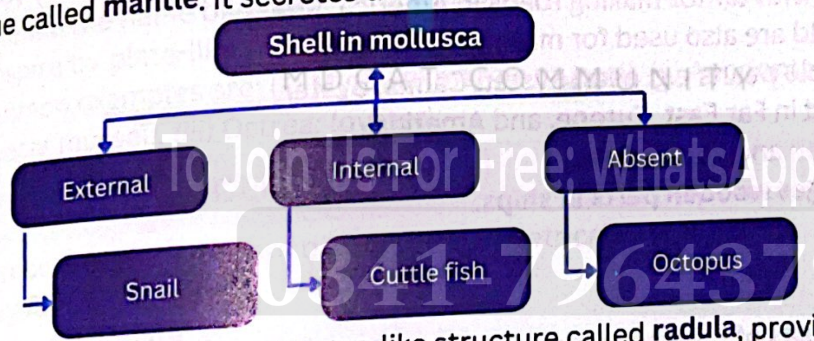
# PHYLUM MOLLUSCA

## THE GENERAL CHARACTERISTICS

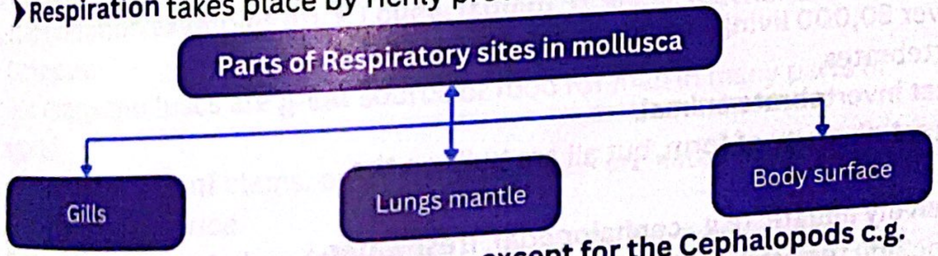
- Latin; Moallis, soft




- The molluses are **bilateral symmetry**, triploblastic, coelomate, **soft and unsegmented animals.**
- Body is divided into; head **ventral muscular foot** dorsal visceral region containing most of the internal organs.
- The whole animal is covered in an envelope of glandular epithelial tissue called **mantle**. It secretes the shell.



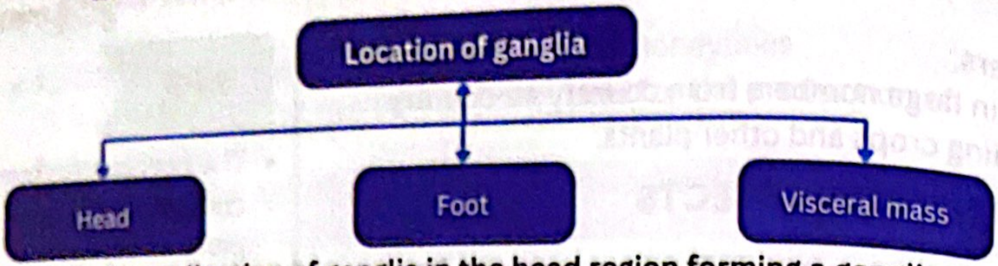

- Mouth Cavity may have a tongue-like structure called **radula**, provided with horny teeth e.g. Cuttle fish, snail.
- **Respiration** takes place by richly provided blood vessels




- **Circulatory System** is of open type **except for the Cephalopods c.g. Squids.**
- Coelom is divided into **haemocoelic channels** or sinuses.
- The **excretory system** consists of one or two **metanephridia.**
- **Nervous System** consists of three pairs of interconnected ganglia.

**KPK**

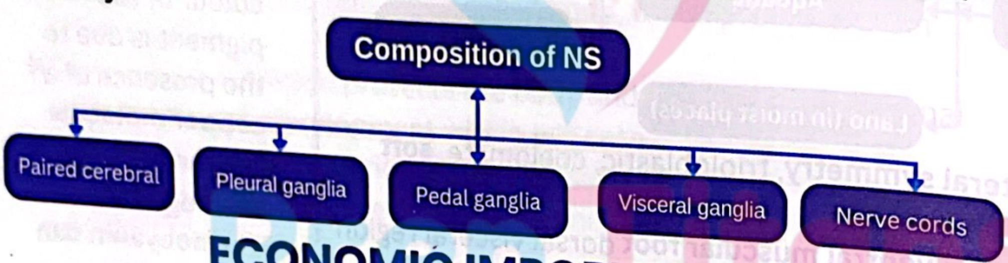
- **The nervous system consists of three pairs of orange coloured gangila connected by nerve cords.**
- **The testes are white and ovaries are of reddish colour.**
- **Fertilization is external.**
- **In certain molluscs like octopus and cuttle fish a blue coloured respiratory pigment haemocyanin is present. The blue colour of the pigment is due to the presence of a copper molecule (as iron in haemoglobin).**
- **Haemocyanin can transport three times more oxygen as compared to haemoglobin.**




- There is a collection of ganglia in the head region forming a ganglionic mass. e.g. Squids.
- Sexes may be separate e.g. Unio or united eg. Helix. The development takes place through **trochophore larvae.**

# EVOLUTIONARY ADAPTATION IN MOLLUSCS

- Most of the diversity among molluscs is related to their adaptation to different habitats and modes of life and to a wide variety of feeding method ranging from sedentary filter feeding to active predation
- **Digestive system** is complex having rasping organ radula and anus usually emptying into mantle cavity.
- **Gaseous exchange** by gills, lungs mantle or body surface.
- **Open circulatory system** consists of heart and blood vessels. **In cephalopods mostly closed circulatory system is present.**
- There are one or two metanephridia, which open into the pericardial cavity.



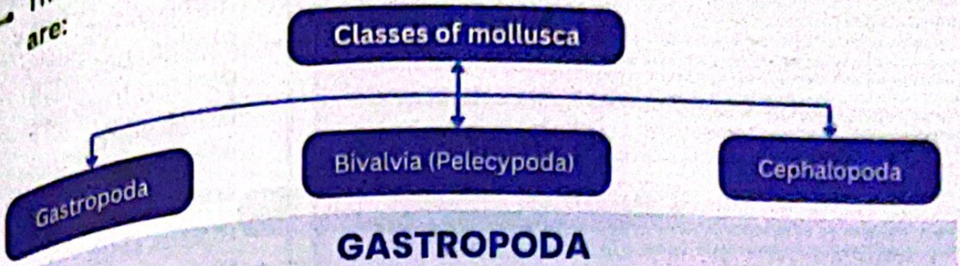

# ECONOMIC IMPORTANCE

- Shell of freshwater mussels are used in button industry.
- Shells of oyster are mixed with tar for making roads in America. Shells in certain parts of the world are also used for making ornaments.
- Some oysters make valuable pearls e.g. pearl oyster. Calms, oyster, mussels are source of food in Far East, Europe, and America.
- Slugs are injurious in garden and cultivation.
- **Toredo a shipworm damages wooden parts in ships.**

**PTB**

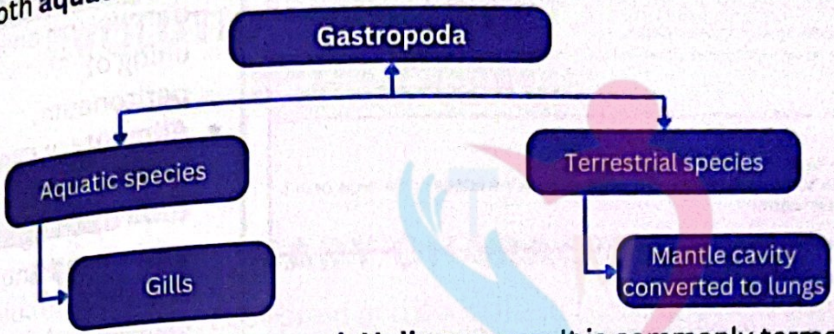
- The phylum Mollusca consists of diverse group of organisms which include slow-moving snails and slug, bivalved clams, and **highly active cephalopods.**
- The phylum includes over **50,000 living species** and is the **second largest** phylum of invertebrates,
- **Giant squid is the largest invertebrate animal.**
- Molluscs also show a great diversity of form, but all are built on the same basic plan.
- Some groups are **exclusively aquatic (e.g., cephalopoda)**, freshwater or marine. The others include terrestrial animals (land snail) living mostly in moist places.
- **A respiratory pigment of blue in color, called haemocyanin is present.**
- The organ of locomotion is a **muscular foot,** however in many ...

the movement is slow. The others are sessile i.e. unable to move. The molluscs are classified into six classes. The three major classes are:




## GASTROPODA

- These are asymmetrical and their body is covered with usually coiled one piece shell.
- The animal can withdraw itself into the shell.
- **Both aquatic and terrestrial species are included in this class.**




- The common examples are: **i. Helix aspersa:** It is commonly termed garden snail. **ii. Limax:** the slug

## BIVALVIA (PELECYPODA)

- This class includes bilaterally symmetrical aquatic molluscs.
- The body is laterally compressed and is enclosed by two pieces of shells hence the name bivalves.
- They respire by plate-like gills.
- The common examples are: (1) Mytilus: (marine mussel). (ii) Anodonta: (freshwater mussel), (iii) Ostrea: (oyster).



## CEPHALOPODA

- The members of this class are bilaterally symmetrical with dorso-ventrally flattened body.
- All species are aquatic.
- The shell is much reduced and internal. In most cases it is absent.
- The animals are highly developed and active. Slug Land snail
- The common examples are **i. Loligo: (squid). ii. Sepia: (cuttlefish). iii. Octopus.**
- But many molluscs are great source of food for man in many parts of world.
- Large quantities of clams, oysters and mussels are eaten in Far-east, Europe and America.
- **Oysters are regarded as delicacy**

# PHYLUM ECHINODERMATA

## GENERAL CHARACTERISTICS

| Feature | Explanation |
|---|---|
| General Characteristics | • The Echinodermata are exclusively marine and most of them are found at the bottom along shorelines in shallow seas.<br>• Most species are free moving however some are attached to the substratum.<br>• The body is covered by delicate epidermis.<br>• Echinoderms are triploblastic coelomates and exhibit radial symmetry.<br>• The mouth is on lower surface (oral) and anus is on upper surface (aboral). |
| Larval Forms & Symmetry | • All the larval forms of these animals exhibit bilateral symmetry, but the adults show radial symmetry with their special mode of life. |
| Body Forms | • The body may be flattened like starfish (sea star), star-shaped with short arms (brittlestar), star-shaped with long arms (basket star) or elongated (sea-cucumber). There is a central disc from which arms radiate. |
| Reproduction | • The sexes are separate, and the fertilization is external. |
| Water Vascular System | • The most unique characteristic of echinoderms is that a water vascular system is present in their coelom.<br>• It is a complex system of tubes and channels surrounding the mouth and passing into the arms or radiating branches.<br>• The water circulates through these spaces.<br>• Water enters the animal through a sieve-like plate called madreporite on the upper side. |
| Movement & Tube Feet | • The mobile species move with the help of tube feet.<br>• The tube foot is a small structure that can present along the edges of the arms or in 5 distinct ambulacral regions. |
| Nervous, Circulatory & Excretory | • The nervous system is also very simple.<br>• There is no circulatory or excretory system. |
| Regeneration | • Similarly, the ability to replace lost organs is common in echinoderms, known as regeneration. |
| Examples | • Asterias (starfish), Sea urchin, Sea cucumber, Cake urchin, Brittle star |



**PTB**

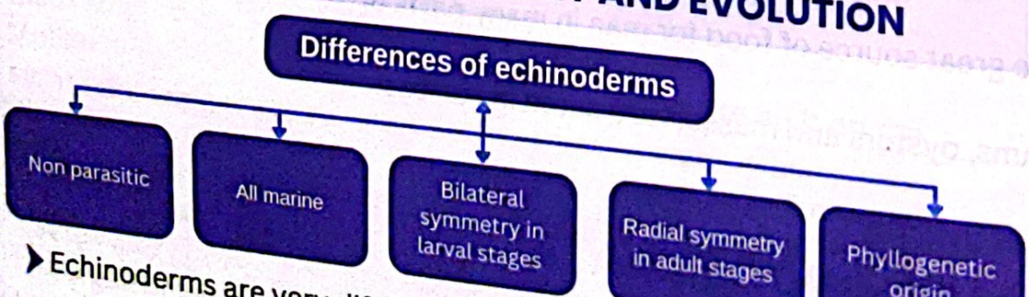
- There are over **5,000 known species** of echinoderms. They are marine organisms living at the sea bottom.
- The **mesodermal cells develop a firm calcareous endoskeleton** which may bear spines and because of its origin, from mesoderm it is called **endoskeleton**.



**FTB**

- Echinoderms have an endoskeleton consisting of a spine bearing calcium rich plates. The spines, which stick out through the delicate skin, account for their name.
- The **regeneration** is shown by the **adult** and **larval stages**.

## ECHINODERMS ANCESTORY AND EVOLUTION




- Echinoderms are very different from other phyla.

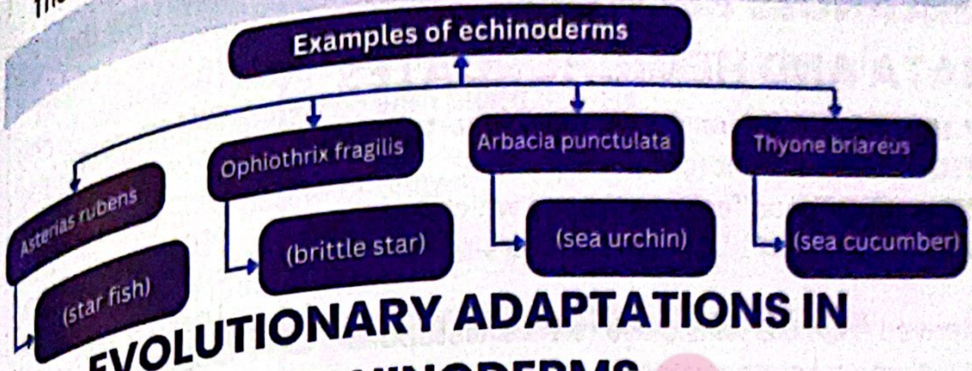
**KPK**

- Name of the phylum has been derived from two Greek words; **ekhinos means spine and derma means skin.**
- Usually, five arms are present.
- The body consists of an outer epidermis, a middle dermis and an inner lining of peritoneum.
- **Alimentary canal usually a coiled tube** opening at mouth and anus.
- A typical circulatory system is present also called **heamal system.**
- The digestive system of echinoderms consists of a short coiled tube, the alimentary canal with **ten pairs of pyloric caecae,** the **digestive glands.**
- All echinoderms including starfish are **carnivores.** Food mainly consists of molluscs such as oysters, clams, mussels etc.
- Fish, crabs and other small animals are also taken as food. **Tube feet help to capture prey.**
- Respiration occurs through a variety

## WHY BRITTLE STAR CALLED SO?

- Brittle star is called brittle because it **can break off its arm if it is injured.** This "autotomy" allows the animal to leave its arm behind and escape from an enemy to save life. The broken arm regenerates rapidly into a new brittle star.

## EXAMPLES




## EVOLUTIONARY ADAPTATIONS IN ECHINODERMS

FTB

### EVOLUTIONARY CHARACTERISTICS

1. **Radial symmetry**: Lost brain and specialized sense organs in adoption of radial symmetry.
2. **Water vascular system**: Unique system for movement, feeding, and respiration.
3. **Dermal endoskeleton:** Provides support and protection.

### BODY FEATURES & STRUCTURE

1. **Creeping benthic forms:** Many echinoderms are slow-moving, bottom-dwellers.
2. **Filter feeding, deposit feeding, scavengers, and herbivores:** Diverse feeding habits.
3. **Few predators:** Relatively low number of predatory echinoderms.
4. **Large pelagic forms:** Some echinoderms are large and ocean-dwelling.



### INTERNAL SYSTEMS

1. **Digestive system:** Usually complete, axial, or coiled; anus absent in ophiuroids.
2. **Respiration**: Dermal branchiae, tube feet, respiratory tree, and bursae.
3. Blood vascular system: Much reduced.
4. **Excretory organs:** Absent.
5. **Nervous system:** Circumoral nerve ring and radial nerve cords; no brain.

## RESEMBLANCES BETWEEN ECHINODERMATA AND CHORDATES

- The **echinoderms** are comparatively **simple** in structure, organization and physiology, and deserve a place slightly below the annelid worms. However, these are placed at the top of the list of invertebrate phyla.

fishes, peristomical gills in sea urchins, genital bursae in brittle star and cloacal respiratory tract in sea urchins. Tube feet also help in respiration.

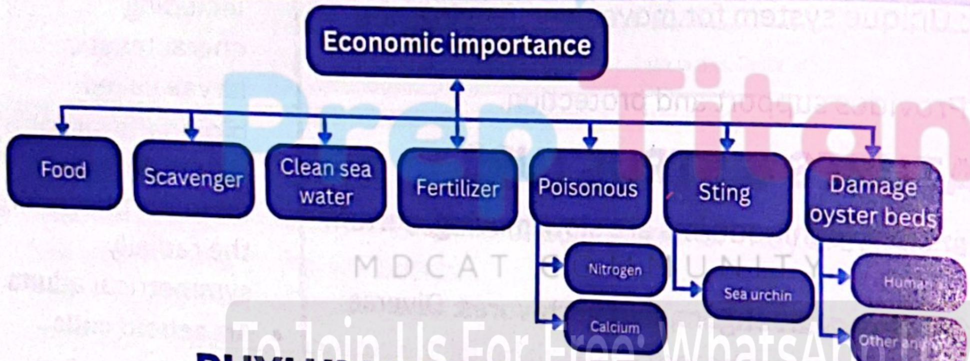
- **A nervous system is primitive consisting** of network concentrated into the radial ganglia containing nerve chords.
- Sense organs are poorly developed.
- Sexes are usually separate with few exceptions. **Reproduction** is usually **sexual.**
- **Development is indeterminate** including characteristic larvae called **bipinnaria larva** which undergo metamorphosis into the radially symmetrical adults.
- **Amoeboid cells known as amoebocytes** roaming about in coelomic fluid absorb waste material and make their way out through the wall of rectal cecae. Amoebocytes are **constantly produced** in the **body** for this purpose.
- Beside many nerve cells which lie among the

- This is because there are several striking resemblances, between the echinoderms and chordates, such as:


## RESEMBLANCES BETWEEN ECHINODERMATA AND HEMICHORDATES

- Echinodermata do not **show close relationship to most invertebrates, but they do show affinities with hemichordata.**
- Both these have a number of common features among which are the **formation of coelom and retention of blastopore** as the site for future anus.
- In both mesoderm is derived from the cells close to the blastopore.
- Both possess mesodermal **endoskeleton** whereas the **exoskeleton** is **ectodermal in origin** while in invertebrates the blastopore develops into mouth.
- The above resemblances between two phyla are neither accidental nor due to convergent evolution but are because the two are closely related and both emerged from the **same (common) ancestor**.

## ECONOMIC IMPORTANCE




## PHYLUM HEMICHORDATA

### GENERAL CHARACTERISTICS

| Characteristic | Description |
|---|---|
| Combined Features | Have both Echinoderm and Chordate characteristics. |
| Deuterostome Group | Along with Echinoderms and Chordates, belong to the deuterostome branch of the animal kingdom. |
| Protochordates | Called protochordates due to their close relationship with chordates. |
| Body Form | Soft-bodied, worm-like animals. |
| Body Division | Divided into proboscis, collar, and trunk. |
| Body Wall | Ciliated epidermis with mucous-secreting cells. |
| Digestive Tract | Straight digestive tract (may show variations). |
| Coelomic Cavities | Present in each of the three body regions (proboscis, collar, trunk). |
| Circulatory System | Has a median dorsal and a median ventral vessel. |
| Respiratory System | Gill slits forming a dorsal row behind the collar. |
| Excretory System | Likely a glomerulus connected to blood vessels. |
| Nervous System | Sub-epidermal plexus of cells and fibers. |
| Examples | Balanoglossus, Saccoglossus. |

epidermal ce... radial nerve co... runs along th... ambulacral gro... and unites wit... nerve ring encircling the mouth.

- The apical nerv... system consis... a trunk in each a... which meets th... other trunk at th... center of the d... These trunks innervate the dorsal muscle o... the arm.
- The tube feet are the principal sen... organs. They receive nerve fib... from the radial nerve cord at the end of each radia... canal, the radial nerve cord ends i... pigmented mass known as the eye which is a light perceiving organ.

**BTB**

- The Phylum name was given by **Leukert** in 1847.
- These are **unisex...** and **development indirect.**
- Echinoderms are the first and only invertebrates wh... are deuterostome... therefore, these a... placed at the top... invertebrates, ne... to chordates.

**FTB**

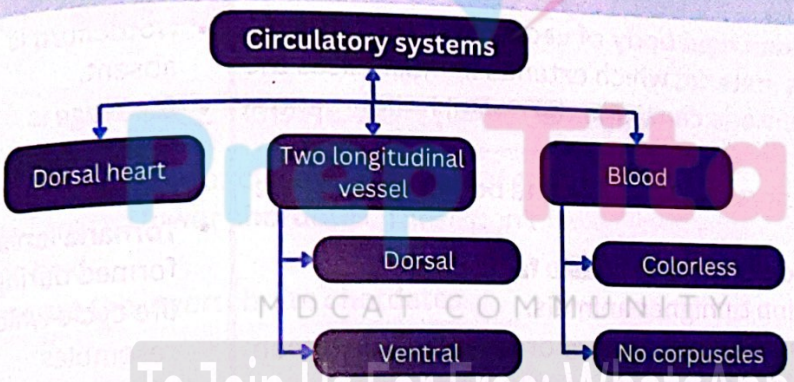
- The hemichordates are called **acorn worms.**
- All hemichordates are **marine.**
- Some are solitary, naked, and slow-moving others are sedentary.
- Body is **unsegmented.**
- Symmetry is **bilateral** and hemichordates are **triploblastic.**
- Body cavity is a **true coelom.**
- The excretory system comprises of a glomerulus situated in the proboscis and connected with blood vessels.
- There is **no nephridia.**
- Sexes may be separate or united.
- **Fertilization is external.**
- Development may include free swimming larval stage.

# EVOLUTIONARY ADAPTATIONS OF HEMICHORDATA

## RESPIRATION

- t occurs by gill slits connecting the pharynx with outside as in chordates

## CIRCULATORY SYSTEM






## NERVOUS SYSTEM

- It is **diffused** consisting of an epidermal plexus of nerve cells and nerve fibers.

**BTB**

- They are also called **Tongue worms.**
- **So far only 70 species** of them have been recorded.
- Hemichordates were earlier placed in chordates as a group, but now they are placed in a separate phylum.
- Although these animals have some chordate like characters such as deuterostome, pharyngeal gill slits, a dorsal nerve cord (some time may be hollow).
- However, lack a complete chordate like notochord, Blood vascular system is non chordate like i.e., dorsal heart, epidermal nervous system like non-chord

**KPK**

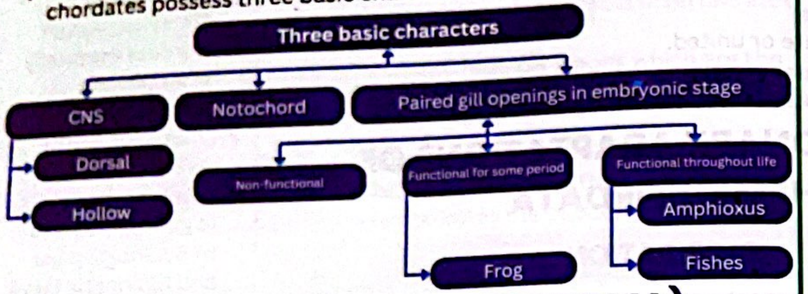
**PHYLUM ECHINODERMATA**

- Although they are very different from all invertebrate phyla, still they have a strong affinity to phylum chordate especially to subphylum Hemichordata.
- **Ciliated larvae of certain Hemichordates** (e.g., Tonaria larva of Balanoglossus) and bipinnaria larva of echinoderms are very much similar in shape and structure.
- **The pattern of cleavage of fertilized egg,** formation of **mesoderm, anus, mouth and coelom in echinoderms & hemichordates is similar.**
- **Creatinine phosphate in the muscles of both echinoderms and chordates are similar which produce energy for muscular activity.**
- Based on these similarities the echinoderms and chordates appear to be closely related and evolved from a common ancestor.

# PHYLUM CHORDATA

## GENERAL CHARACTERISTICS

- This great phylum derives its name from one of the few common characteristics of the group - The notochord.
- This structure is possessed by all members of the phylum either in the larval or embryonic stages or throughout life.
- The chordates show great variety and inhabit all kinds of habitat. All chordates possess three basic characters which are as follows:




## AMPHIOXUS (BRANCHIOSTOMA)

**PTB**

- The **notochord** is a **rod-like semi rigid body** of vacuolated cells which **are filled with proteinaceous material** which extends in most cases the length of the body between enteric canal and the dorsal hollow central nervous system.
- Its **primary purpose** is to **support** and to **stiffen the body** that is to **act as skeletal axis.**
- It seems that the **endoskeleton** is the **chief basic factor** in the development and specialization of higher animals.
- The animals most familiar to us belong to the chordates including man himself.

**FTB**

- The representatives of phylum Chordata called the chordates, are the most familiar, adaptable and the successful and the most widely distributed animals, showing diversity of form, habitat, and habits.
- Chordates have **four basic characteristics:**

## NOTOCHORD

- The notochord is a solid unjointed rod located in the mid-dorsal line between the gut and the central nervous system outside the coelom.
- The notochord serves as an axial endoskeleton, giving support to the body and providing space for muscle attachment.
- In some lower chordates the notochord persists throughout life, but in higher chordates it is partly or wholly replaced in the adult stage by a jointed backbone or vertebral column, which is segmented.

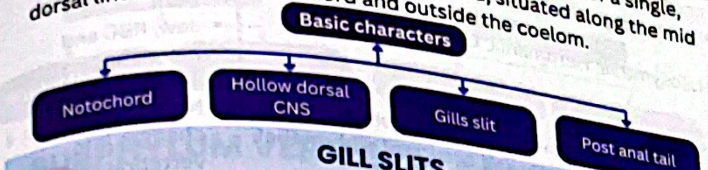
**KPK**

- Hemichordates are worm-like animals found in shallow ocean bottom.
- The body is divided into three regions, an anterior protosome, middle mesosome and posterior metasome or proboscis, collar and trunk.
- Digestive tract consists of a long-coiled tube.
- Brain occurs in the mesosome, and the main nerve tracts are present in mid dorsal and mid ventral line.
- **Notochord** is absent.
- **Cleavage** is **holoblastic** and radial.
- **Tornaria larva** is formed during the life cycle which resembles bipinnaria larva of echinoderms.
- Many hemichordates **make colonies.** E.g., Saccoglossus kowalevskii, (Acron worm).



## DORSAL HOLLOW CENTRAL NERVOUS SYSTEM

- The central nervous system of all the chordates consists of a single, tubular fluid filled, non-gangliated nerve cord, situated along the mid dorsal line above the notochord and outside the coelom.




## GILL SLITS

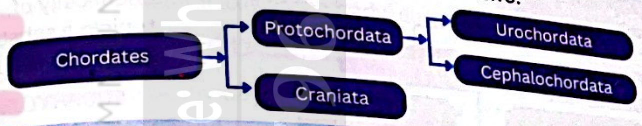
- The pharyngeal gill slits (pharyngeal pouches) are paired perforations on the lateral sides of the anterior part of the body, leading from the pharynx to exterior.

## POST ANAL TAIL

- It extends beyond the anus; present at least in embryo; regresses (passage back, reversion) into tail bone in humans.

# CLASSIFICATION OF CHORDATES

- The phylum chordata has been sub divided into two:




## PROTOCHORDATA(ACRANIA)

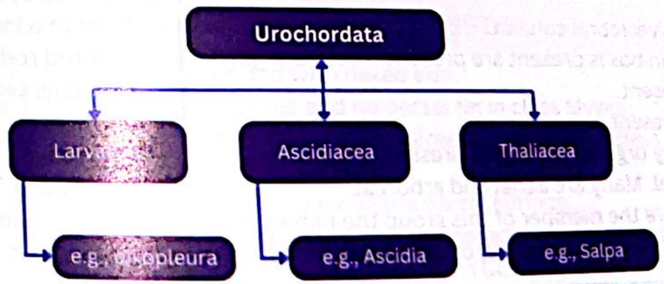
- In this brain is not enclosed in a bony case.
- These are the **lower chordates**. These don't have a cranium (skull or brain box)
- These are the invertebrate chordates.

## CRANIATA

- In this case the brain is enclosed in a bony case called cranium due to which they are called craniates and notochord has been replaced by vertebral column.
- They are the higher chordates.
- They are vertebrate chordates.

# GROUP PROTOCHORDATA (ACRANIA)

- GROUP PROTOCHORDATA (ACRANIA)




**KPK**

- Notochord is a dorsal stiff rod.
- Gill slits are also called perforated pharynx.

**BTB**

- A **notochord** is an unjointed solid skeleton, placed above the alimentary canal and below the dorsal body wall and central nervous system appeared in the embryo of all chordates.
- **Pharyngeal Gill slits and gill pouches** are paired sets of openings in the pharyngeal region, in aquatic chordates it persists and functions as respiratory organ but in terrestrial vertebrates it is replaced into Eustachian or auditory tube, Parathyroid, tonsils and thymus.

## SUBPHYLUM UROCHORDATA

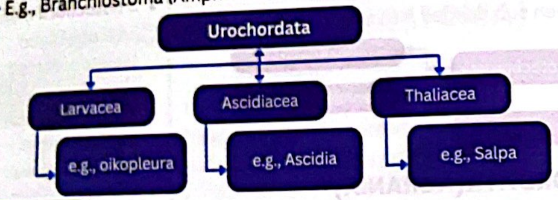
- Notochord and nerve cord only in the fee-swimming larvae. Adults are sessile and enclosed in a covering called tunic. Therefore, they are also called tunicates.
- E.g., Molgula, Ascidia, Halosymthia, Herdmania, Ciona intestinalis.

**FTB**

- On the outside are two projections: the incurrent siphon which corresponds to the anterior end of the body and excurrent siphon that marks the dorsal side.
- Larva has a mid-dorsal supporting rod, the notochord, in the tail, so the group has been named urochordata (uro means tail). The notochord usually disappears during metamorphosis, so that adult has no skeleton.

## SUBPHYLUM CEPHALOCHORDATA

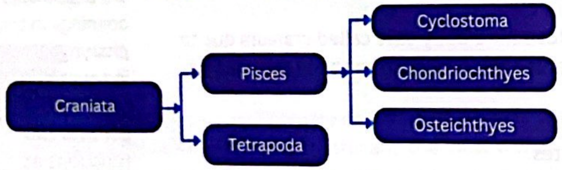
- Notochord and nerve cord extend along the entire length of the body and persist throughout life.
- E.g., Branchiostoma (Amphioxus)




**FTB**

- Body is fish like.it has no head but tail is present.
- There is no organ for respiration.

## GROUP CRANIATA




- It has only one sub-phylum i.e., vertebrata

## SUBPHYLUM VERTEBRATA (CRANIATA)

- Notochord replaced into vertebral column.
- Brain and cranium or brain box is present are present. Teeth and jaws are present. RBCs are present.
- Paired appendages are present.
- Kidneys are their excretory organs. Tail is also present.
- Either aquatic or terrestrial. Many are aerial and arboreal.
- The characteristics that give the member of this group the names "vertebrata" and "craniata" are spinal column of vertebrae, which

**BTB**

- The term Acrania means without skull.
- Jaw, RBC and paired appendages are absent.
- Notochord never changes into vertebral column.

**BTB**

Nerve cords also disappear in the adults, only dorsal ganglion is present.

**KPK**

Tunic is made chemically of tunicin a substance related to cellulose.

**SUBPHYLUM CEPHALOCHORDATA**

**BTB**

- Cephalo means head.
- Notochord runs mid dorsally throughout the body.

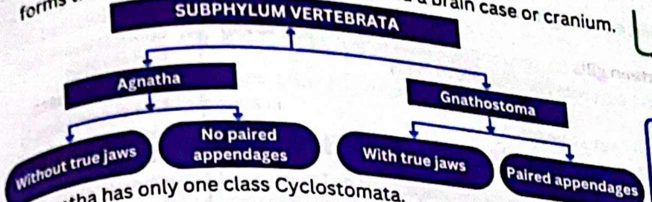
**KPK**

- **Notochord** is well **developed** in adults.
- Their body is in the form of a long, pointed rod, hence called as **sea lancelet.**
- They have a hollow nerve cord. They are free living and swim about in



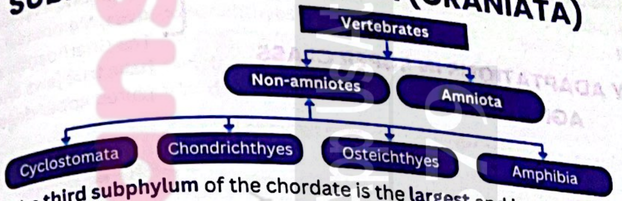


forms the chief skeletal axis of the body, and a brain case or cranium.




- Agnatha has only one class Cyclostomata.

## SUBPHYLUM VERTEBRATA (CRANIATA)



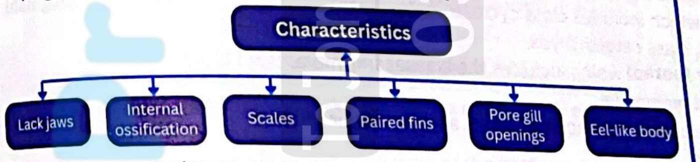

- The **third subphylum** of the chordate is the **largest** and imminently diverse vertebrata,
- The characteristics that give the member of this group the names "vertebrata" and "craniata" are spinal column of vertebrae, which forms the chief skeletal axis of the body, and a brain case or cranium.

## CLASSIFICATION

- Vertebrates may be divided **into non-amniotes** or those without foetal membrane and amniota.


## SUPER CLASS AGNATHA

- The living members of agnatha are divided into two classes: Mixini (hagfishes) and Cephalospidomorphi (lampreys)




- In other aspects however, the two groups are morpho- logically very different.

## THE GENERAL CHARACTERISTIC

- Body slender, eel-like, rounded with naked skin.
- There are no paired appendages and no dorsal fin in class Myxini.
- There are one or two median fins and no paired appendages in class Cephalospidomorphi.
- The caudal fin extends anteriorly along the dorsal surface.
- Skeleton is fibrous and cartilaginous, and the notochord is persistent.
- Biting mouth with two rows of eversible teeth in Class Myxini and the

water.
They are filter feeders.

**BTB**

- In vertebrates Notochord replaced into vertebral column.
- Teeth and jaws are present.
- RBC is present.
- Kidneys are their excretory organs.
- Tail is also present.
- Many are aerial and arboreal.
- The vertebrate chordates are divided into **two super classes:** Agnatha and Gnathostomata.
- The Agnatha are without true jaws and no paired appendages.
- Gnathostomata with true jaws and paired appendages.
- **Class Cyclostomata:** (Cyclo; circular, stoma; mouth, because their mouth is circular).
- These fishes are without true jaws and the **most primitive group** of living vertebrate.
- Two chambered venous heart and many aortic arches.
- Digestive system **without stomach**
- Cyclostomes have single testis or single ovary and without ducts.

oral disk is sucker like and tongue with well-developed teeth in class Cephalospidomorphi.

- There are **five to sixteen gills** for respiration in class Myxini and **seven pairs of gills each** with external gill opening in class Cephalospidomorphi.
- Digestive system is without stomach.
- Dorsal nerve cord with differentiated brain.
- Sexes are separate.
- Fertilization is external and there is no larval stage.
- The examples of Agnatha are Hagfish, and Lamprey.
- Seven parts of gill apertures.
- No paired appendages.

## EVOLUTIONARY ADAPTATIONS IN SUPER CLASS AGNATHA

- Body is long slender limbless, slimy skin offer minimum resistance to water.
- Laterally compressed, tail with caudal fin provides greater forward thrust. Buccal
- funnel and toothed tongue form a device for blood sucking in absence of jaws.
- Ability to draw in and expel out water through the gill slits carries on respiration.
- Very large numbers of eggs are laid. Burrowing life of the larvae gives them protection against carnivores and filter feeding best suits their nearly sedentary life in burrows.

**PTB**

- It includes animals which have cranium in which the brain is enclosed. It includes animals with vertebral column that means that all chordates in this, group are under subphylum vertebrata and are therefore vertebrates
- It is customary to place vertebrates **into two super classes.**
  1. **Pisces (Fishes)** which includes class cyclostomata, class chondrichthyes, class osteichthyes.
  2. **Tetrapoda (Four footed)** which includes the classesamphibia, reptilia, aves and mammalia.
- The former is made up of strictly aquatic forms and the latter of the land dwelling animals.
- The class cyclostomata includes most primitive living vertebrates which are without jaws. This distinguishes them from the rest of the vertebrates.
- Scales absent.
- No paired appendages.
- Cartilaginous Skeleton.
- Ventral Suctorial mouth.
- Heart with one auricle.
- Six to fourteen pairs of gills.
- Digestive system lacks stomach.
- Sexes are separate in lampreys.

- All vertebrates are chordates, but all chordates are not vertebrates
- **Gnathostomata** This super class is divided into **six classes,** (Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves, Mammalia). The Gnathostomes have true jaws and paired appendages.

**KPK**

- Fishes are the largest group of vertebrates and constitute about 4_ **% of the total vertebrates.**
- The number of living fish species is more than 29000.
- Examples of class cyclostomata or Agnatha are **Petromyzon marinus** (lamprey) and **Maxine glutinosa** (hag fish).





mentr.

- Hag fishes are hermaphrodite.
- Fertilization external and there is a long larval period in Lamprey.

## SUPER CLASS GNATHOSTOMATA

- It is divided into six classes: Chondrichthyes. Osteichthyes, Amphibia, Reptilia, Aves and Mammalia.

## CLASS CHONDRICHTHYES

- **The gnathostomates have jaws.** The tooth bearing bones of the head.
- Jaws are believed to have degenerate character rather than **primitive evolved from the first pair of gill arches of agnathans.**
- Jaws Evolve Thechondrichthyes are popularly called the **cartilaginous fishes.**
- The cartilaginous skeleton is considered as a character.
- It includes the sharks. dogfishes, rays, skates and chimaeras.

**Class Chondrichthyes**

**BTB**

- They have heterocercal tails in which dorsal lobe is longer than ventral lobe.
- Most of them are **carnivorous** sharks are very active hunters.

### THE GENERAL CHARACTERISTICS

| Characteristic | Details |
|---|---|
| Body | Laterally compressed and spindle (fusiform) shaped |
| Mouth | Ventral |
| Olfactory Sacs | Not connected to the mouth cavity |
| Skin | Tough, covered with minute placoid scales |
| Fins | Pectoral and pelvic fins are paired |
| Endoskeleton | Entirely cartilaginous |
| Digestive Tract | Leads into the cloaca; stomach is J-shaped |
| Circulatory System | Two-chambered heart (one atrium, one ventricle) with 5–7 pairs of aortic arches |
| Respiratory System | 5–7 pairs of gills, without an operculum |
| Swim Bladder | Absent |
| Reproduction | Sexes are separate; gonads are paired; fertilization is internal; most forms are oviparous or viviparous |
| Skates and Rays | Bottom dwelling; pectoral fins are greatly enlarged and function like wings |
| Sting Rays | Tail is long and whip-like with sharp spines capable of inflicting dangerous wounds |
| Electric Rays | Dorsal muscles are modified into a powerful electric organ that can deliver severe shocks to stun prey |

### EVOLUTIONARY ADAPTATIONS

- Spindle shaped body, slippery skin, presence of scales on the body protects the animal.
- **Ventral mouth** is suited for capturing prey at the bottom of the sea. Internal fertilization, nourishment and protection of the embryo in the mother's body are evolutionary adaptive feature.

### ECONOMIC IMPORTANCE

- They provide food.
- Some shark and rays are eaten in many countries. They provide products of commercial value.
- Oil is obtained from the liver ofmany sharks, **which is a source of vitamin A and D.**

**FTB**

- Shark skin leather is used for shoes and bags
- Pituitary gland of shark yields an extract of medical use.
- Sharks feed on crustaceans, lobsters, crabs, and other fishes, which form human food.
- There are two dorsal fins. The caudal fin is **heterocercal.**

**PTB**

- The cartilaginous skeleton is considered a degenerated character rather than primitive character.
- With the exception of whale, the sharks are the largest living vertebrates, some reaching **30-50 feet in length.**

# CLASS OSTEICHTHYES

| Characteristic | Bony Fishes | FTB |
|---|---|---|
| Skeleton & Vertebrae | Bony skeleton replaces the cartilaginous one; notochord may persist in reduced form. | Numerous vertebrae; pelvic girdle often absent. |
| Skin & Scales | Skin has embedded dermal scales (ganoid, cycloid, or ctenoid); no placoid scales. | Spiracles are mostly lacking. |
| Fins | Fins (both median and paired) with rays of cartilage or bone. | Caudal fin is homocercal. |
| Mouth & Jaws | Mouth is terminal and variable in shape; jaws may have teeth or not. | Mouth is usually terminal with numerous teeth; jaws are well developed. |
| Respiratory System | Respiration via gills supported by bony gill arches and covered by an operculum. | Four pairs of gills supported by bony arches. |
| Swim Bladder | Usually present; aids in buoyancy (may or may not connect with the pharynx). | |
| Heart & Circulation | Two-chambered heart (one atrium, one ventricle); blood contains nucleated red cells; brain with 10 pairs of cranial nerves. | Two-chambered heart with four pairs of aortic arches; red blood cells are oval. |
| Reproduction | Sexes are separate; gonads are paired; fertilization is usually external. | Most are oviparous, with some ovoviviparous or viviparous forms; anus is present, and cloaca is absent. |
| Examples | Trout, cod, carp, catfish. | |

**Class Osteichthyes**

**BTB**

- Mostly possesses bony endoskeleton. The stomach is variable in shape.
- Few exhibits internal fertilization.

**KPK**

- These fishes have a skeleton made of bone hence they are called bony fishes.
- They are the most successful group of species and inhabit all types of habitats.

## EVOLUTIONARY ADAPTATIONS

- The body is laterally compressed spindle shaped and has slimy skin, strong segmental muscle for efficient swimming devices. Gills help with respiration.
- Air or swim bladder enables the fish to easily shift from one depth to another.
- Gill rakers check the loss of food.
- Lack of teeth in the jaws is correlated to the herbivorous diet.

## ECONOMIC IMPORTANCE OF OSTEICHTHYES

### BENEFICIAL EFFECTS

- Commercial products
  - Fish oil
  - Fish meat
  - Liquid glue

- Cod liver oil is the source of
- • vitamin A   vitamin D.

- Bony fishes
  - Fresh Water
    - Trout
    - Carp
    - Catfish
    - Mullet
  - Marine bony fish
    - Cod
    - Herring
    - Salmon

# ADAPTATIONS TO AQUATIC LIFE

- The major adaptations are as follows:

## STREAM - LINED BODY (BOAT SHAPED)

- The body of Fish is such that it offers little resistance to water while swimming.

## FINS

- Fins are another important adaptation to aquatic life.

- Types of fins
  - Paired fins
    - Pectoral
    - Pelvic
  - Unpaired fins
    - Dorsal
    - Caudal (tail)
    - Anal fins

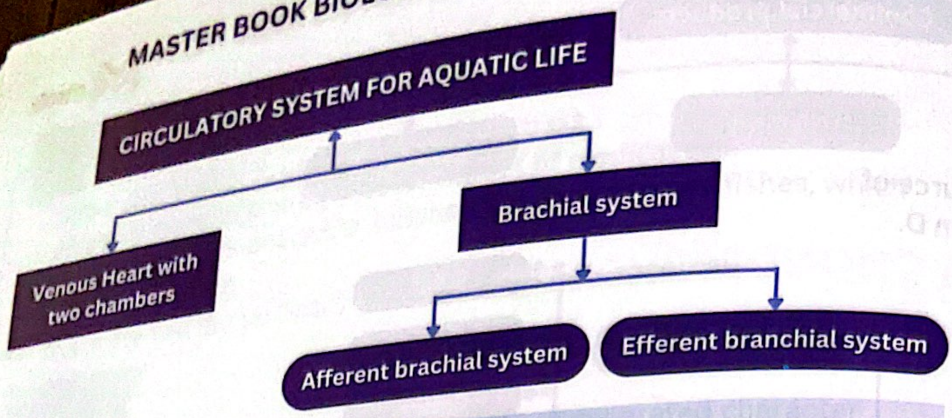


- Fins help in swimming as they keep balance of fish in water.

## SWIM BLADDER

- This is found in most bony Fish except a few; it may or may not be connected to pharynx.
- It is mainly a hydrostatic organ & can change the gravity of fish by filling itself with gas.
- The fish can thus float high or sink lower in water.
- The gases that fill the swim bladder are either oxygen, carbon dioxide and nitrogen and may be secreted by the gland in the swim bladder itself.
- In those fishes in which the swim bladder is connected to pharynx the bladder may be filled by gulping of air.

## CIRCULATORY SYSTEM




## RESPIRATORY SYSTEM

- In most fishes respiratory organs are the gills, adapted to receive oxygen dissolved in water and remove carbon dioxide in water as the gills have network of blood capillaries.

## EXCRETORY ORGANS

- Kidneys of fish are also modified for excretion in the aquatic environment.

## CENTRAL NERVOUS SYSTEM

- Developed central nervous system and sensory organs.

# DIPNOI (A GROUP OF ANCIENT FISH)

- The vertebrates already considered are adapted to strict aquatic life.
- The group of ancient fish known as dipnoi showed modification of aquatic breathing system to meet the conditions of terrestrial life by developing lungs.
- But this case is only an incident in the transition to land.

**FTB**

- All the animals which are called tetrapods have four limbs. The lobe-finned fishes of the Devonian period are ancestral to the amphibians, the first tetrapods.
- Animals that live on land use limbs to support the body, especially since air is less buoyant than water.
- Lobed-finned fishes and early amphibians also had lungs and internal nares as means to respire air.

**TIDBIT**

- A very prominent feature of some fishes is their migration to reach their feeding or breeding grounds. They travel thousands of kilometers in this process. For example, salmon fish.

**PTB**

There are a number of differences between water and land habitats.

1. Oxygen is more in the air than in water.
2. Dissolved substances are present in water for example different kinds of salts.

**KPK**

- Fishes of sub class Dipnoi are called lung fishes.
- There are only three species left in the world.
- These fishes aestivate in the holes dug in the mud for few dry months and during this period respire through the extremely vascularized swim bladder which acts as a lung.
- When the rainy season comes again, they come out and start their normal life in which they respire through gills like other bony fishes.
- Lung fishes is considered to be a connecting link between fishes and amphibians.

3. Temperature changes are more drastic in the terrestrial environment.
4. Land habitat provides a great variety of cover and shelter than aquatic habitat.
5. As a medium water provides greater support to the body than air.
6. Land affords a greater variety of breeding places than does water.

# ADAPTATIONS OF ANIMALS FOR TERRESTRIAL MODE OF LIFE

## COMMON POINTS IN BTB AND PTB

In their transition from aquatic to land environment animals had to undergo modifications or adaptations to cope with the above conditions on land. This included:
1. Development of skin for protection against dry conditions of land.
2. The eggs of land animals are protected by shells from drying and mechanical injury. Also, the size of the egg(yolk) is large to provide space for storage of food.
3. The terrestrial animals developed lungs in place of gills which could take oxygen from air.
4. In connection with the development of lungs there are corresponding changes in the circulatory system to take oxygen from air.
5. For locomotion the paddle-like ins are replaced by jointed appendages modified for walking, running, climbing and lying.
6. Sensory organs have become more advanced and specialized. CNS has become specialized.

## SUPER CLASS TETRAPODA

- These have 2 pairs of jointed limbs.

# CLASS AMPHIBIAN

## GENERAL CHARACTERISTICS

| Characteristic | Description |
|---|---|
| Skeleton & Body Form | Mostly bony skeleton<br>Body form varies greatly (tailed, tail-less, or legless e.g., caecilians)<br>Often possess webbed feet |
| Skin | Smooth and moist<br>Many glands present<br>Scales absent<br>May secrete poisonous substances<br>Pigment cells (chromatophores) |
| Respiration | Larvae use gills<br>Adults primarily use lungs and skin for gas exchange |
| Circulatory System | 3-chambered heart (2 atria, 1 ventricle)<br>Double circulation is present but incomplete |
| Reproduction | Sexes separate - External fertilization common- Larval stage present (tadpoles) |
| Development & Metamorphosis | Larvae transform into adults via metamorphosis<br>Often require water for reproductive cycle |
| Temperature Regulation | Poikilothermic (cold-blooded), may hibernate in winter |
| Habitat | Live in moist conditions or in water<br>Not fully terrestrial due to dependence on water for reproduction |

CLASS AMPHIBIAN

BTB

- Gk.Amphi;both,bios; life
- They usually have two pairs of legs, but some are legless.
- In adults, respiration in a few cases occurs through the gills e.g., in siren.
- They have a five chambered heart (right and left auricle, a single ventricle,sinusvenosus and trunchus arteriosus)
- Fertilization is usually external but in some cases it is internal.
- They are mostly oviparous and exhibit indirect development through metamorphosis.

KPK

- Name of the class has been derived from a Latin word Amphi which means both.
- The animals of this class have characteristics of both aquatic and terrestrial animals.
- Amphibia are considered on the border line of these two groups.
- They breed in water and their

| Examples | Frogs and toads (tail-less)<br>Salamanders (tailed) - Caecilians (limbless) |
|---|---|

**PTB**

- Amphibians are on the borderline between aquatic and true terrestrial animals.
- Devonian fossil evidence suggests a large population of lobefin lungfishes (Dipnoi) lived in shallow freshwater.
- Some of these fishes crawled from one pool to another, spending time on land.
- This behavior gave rise to amphibians—the first vertebrates to come onto land.
- Although amphibians acquired traits for terrestrial living, they retained some aquatic characteristics due to their dependence on water.
- This dual lifestyle is reflected in their structure, which is intermediate between fish and reptiles.
- ·In transitioning from water to land, amphibians developed limbs instead of fins, lungs instead of gills, and modified skin.
- Their circulatory system supports lung respiration, yet larval forms retain gills, aquatic blood circulation, and a digestive system typical of aquatic life.

**FTB**

- Body forms vary but are generally divided into head and trunk; most have two pairs of pentadactyl limbs with four to five (or fewer) digits.
- The skin is highly vascular.
- They are poikilothermic (ectotherms) with variable body temperature.
- **Evolutionary adaptations in amphibians include:**
  - Limbs for movement on solid substrates.
  - ·Lungs for breathing air.
  - ·Internal nares to allow breathing with the mouth closed.
  - ·Slimy skin to protect against desiccation.
  - ·Changes in the circulatory system to support lung and skin respiration.
  - ·A reduction in bones to make the body lighter.

# CLASS REPTILIA

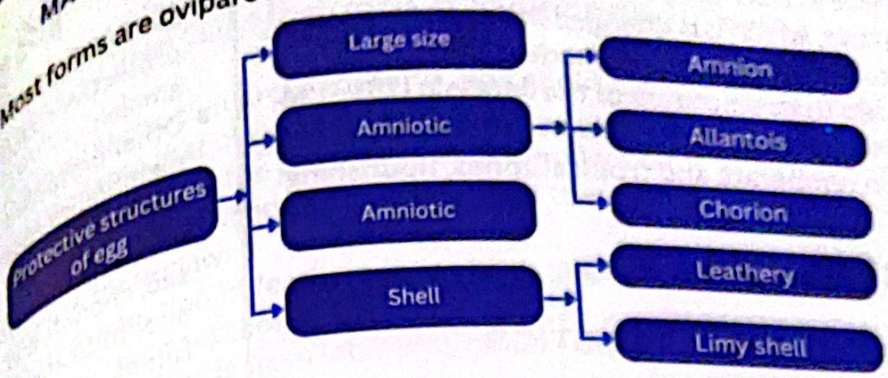
## THE GENERAL CHARACTERISTICS

- Body form varies.
- There are **two pairs of pentadactyl limbs**, each typically with five digits.
- Skin is rough, cornified and dry, which is adapted to land life.
- Heart **is incompletely four chambered**, having two atria and partly divided ventricle
- **Alligator and Crocodiles have completely four chambered heart.**
- Reptiles are cold blooded animals i.e. **piokilothermic**(ectotherms) and hibernate in winter.
- Sexes are separate. Gonads are pai...

larva called tadpole. larva lives in water and respires through gills and swim with the help of their laterally flattened tail.

- After developing gills during metamorphosis, they come out of water and start a terrestrial life.
- In some amphibia like Necturus the gills are retained throughout life.
- They are tetrapods having two pectorals and two pelvic limbs.
- They have webbed feet, but fingers are without claws.
- Heart in amphibia is three chambered; two auricles and a single ventricle. Two additional tubes (sometimes considered chambers) truncus arteriosus and sinus venosus are also present.
- Their circulatory system is not very perfect as mixing of oxygenated and deoxygenated blood takes place in the ventricle.
- Most amphibians hibernate during winter.
- In this process they dig deep in the mud and survive by getting energy from ...

- Most forms are oviparous.




FTB

## EVOLUTIONARY ADAPTATIONS

- Reptiles show the advancement over the amphibians in having:
- a dry skin which enables them to live away from water.
- limbs better suited for rapid locomotion and raising the body off the ground.
- separation of oxygenated and deoxygenated blood in the heart.
- complete ossification of the skill.
- A neck movable independent of the body.
- better mechanism of breathing.
- fertilization is internal.
- egg with shell for protection on land.
- claws for defence.

## THE AMNIOTE EGG EVOLVES

- It is adaptive for land animals to have a means of reproduction that is not dependent on external water.
- Reptiles practice internal fertilization and lay eggs that are protected by a shell.
- The amniote egg contains extra embryonic membrane, which protect the embryo
- One of the membranes, the amnion, is a sac that fills with fluid and provides a "**private pond**" within which the embryo develops.



PTB

- Reptiles have developed a **copulatory organ** necessary for internal fertilization.
- In reptile amniotic eggs, the shell is leathery, resisting dryness and injury.
- Reptiles evolved from amphibians by undergoing these changes, becoming fully terrestrial.
- They flourished throughout the **Mesozoic era (225–65 million years ago).**
- When the climate became less favorable in the **Tertiary period,** most reptile lines became extinct.
- Today's reptiles represent four main lines out of a dozen or more that once existed.

deposited around their kidneys.

**CLASS AMPHIBIAN**

BTB

- Latin. Repere; to crawl.
- Dry non- glandular skin (snakes and lizards) or bony plates (tortoise and crocodile).
- They have four chambered heart (right and left auricle, a partly divided ventricle & **a sinus venosis)**
- Skull with one **occipital condyle.**
- They **respire through lungs** thus predominantly terrestrial and first successful terrestrial group.
- Present day's reptiles have been derived from dinosaurs of Jurassic period **(196- 136 million years before)** and cretaceous period **(136-65 million years ago.**

KPK

- Reptiles are true land vertebrates. Their bodies are bilaterally symmetrical and can be divided in to four regions: head, neck, trunk and tail.
- They are lowest amniotes i.e. their embryos are

- Present-day reptiles include lizards and snakes; the tuatara (Sphenodon) of New Zealand, which has changed little; and crocodiles —an offshoot from the stock that gave rise to modern birds.
- Modern reptiles are derived from dinosaurs of the **Jurassic (195–136 million years ago) and Cretaceous (136–65 million years ago) periods**.
- They predominantly live in temperate and tropical zones, flourishing mainly in the latter.

# CLASS AVES

## THE GENERAL CHARACTERISTICS

| Feature | Key Points |
|---|---|
| Body Structure | Streamlined body; divided into head, neck, trunk, tail; long neck & short tail |
| Limbs & Feet | Two pairs of pentadactyl limbs; forelimbs form wings; hind limbs are strong for perching/walking/swimming; four toes with horny claws |
| Covering & Skeleton | Skin covered with feathers and scales on feet; light skeleton due to air spaces |
| Skull & Beak | Large sockets; jaws form a horny beak; teeth absent |
| Circulation & Respiration | Four-chambered heart; right aorta; endothermic; lungs with air sacs ensure a constant fresh air supply |
| Additional Systems | Syrinx for vocalization; gizzard for crushing food; kidneys excrete uric acid (semisolid urine); internal fertilization with large eggs; one functional ovary/oviduct; some species are flightless (e.g., ostrich, kiwi) |

**FTB**

## EVOLUTIONARY ADAPTATIONS

- An insulated covering over the body.
- Better aeration of blood in the lungs, taking place during both inspiration and expiration.
- Complete separation of venous and arterial blood in the heart.
- Birds have an active life and a high rate of metabolism.
- Very rapid locomotion is provided by the power of flight.
- A regulated body temperature that keeps them equally active all the year round.
- A highly developed power of producing sound. More efficient eyes with double means of accommodation.
- Better ears having cochlea with an **organ of Corti**.
- Patterns of behaviour, such as care for the young ones, nest building, courtship and affection for the mate and migration, which are practically unknown in reptiles.

**PTB**

- Birds are one of the most interesting and most widely known group of animals.
- Birds share with mammals the highest development in the animal kingdom.
- It is believed that both birds and mammals have evolved from reptiles along different lines.

- surrounded by a protective covering amnion.
- Other protective membranes called extra embryonic membranes i.e. yolk sac, chorion, and allontoise are also found.
- Hence there is no larval stage, and the young ones hatch out fully formed from the egg.
- Teeth are present on the jaws except in turtle and tortoise.
- Gill slits appear during embryonic stages but gills never
- Most of the Lizards never take water in their life. They survive with conserving the water present in their food.
- Excretory organs **are metanephric kidneys**.
- Being adapted to live on land they **are uricotelic** i.e. excrete uric acid crystals to conserve water.

**CLASS AMPHIBIAN**

**BTB**

- Latin: avis; Bird
- The important discovery of two **Jurassic (144-208 million years ago)** birds: Archaeopteryx preserved in British

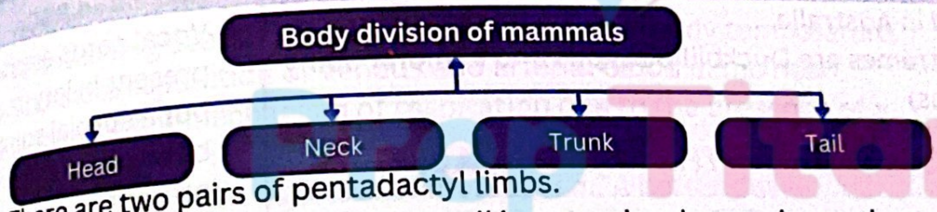
- **The earliest known bird fossil is that of archaeopteryx, two species of** which have been found from rocks of Jurassic period of earth's history.
- The fossil shows that archaeopteryx, was about the size of a crow with skull similar to that of present-day birds.
- It had bony teeth in the jaw socket unlike modem birds which do not have teeth. Jaws extended into a beak and there was a long tail. Each wing had three claws.
- With the exception of feathers these birds showed resemblance to the dinosaurs (giant reptiles of the past).
- Many fossils of birds from later eras of earth history have also been found that had teeth. The above evidence suggests that **birds evolved from reptilian ancestors.**
- The archaeopteryx and others had characteristic of both reptiles and birds and **therefore form a connecting link between the two distinct groups.**
- **In eagle both ovaries and oviducts are functional.**
- These are warm-blooded **(homeothermic).**
- The lungs have extensions known as air-sacs which extend into the bones also.
- syrinx it is situated at the lower end of trachea near the origin of the two bronchi.

1. museum London.
2. Archaeornis, preserved in Berlin Museum Germany, provided evidence of connecting link between birds and reptiles.

- Single occipital condyle.
- Bones are not pneumatic.
- Except feathers fossils birds showed great similarity with dinosaurs
- Bipedal locomotion and hind limbs are also modified for perching.

# CLASS – MAMMALIA

## THE GENERAL CHARACTERISTICS



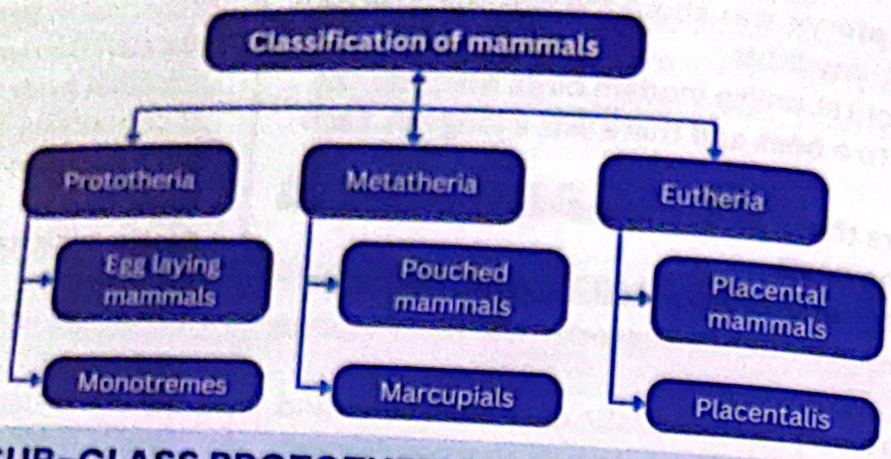

- There are two pairs of pentadactyl limbs.
- These are variously adapted for walking, running, burrowing and swimming or flying.
- Skin is glandular, mostly covered by hair.
- Coelom is completely divided into anterior smaller thoracic cavity and posterior larger cavity by a muscular partition the diaphragm, which is present only in the mammals.
- Endoskeleton is fully ossified. Skull has two occipital condyles, large cranium.
- Each half of the lower jaw consists of a single one. thedentry and articulates directly with skull.
- External ear or pinna is present. There is a chain of three pairs bones in the ear incus, malleus and stapes
- Only left aortic arch is present. RBC are non-nucleated.
- Mammals are warm blooded (endothermic) animals.
- Voice apparatus is well developed and consists of larynx and epiglottis.
- Mammals give birth to their young ones.
- Mammals feed them on milk produced by mammary glands of mother.

**KPK**

- Birds are unique among vertebrates in having feathers on their bodies.
- Both birds and mammals are considered to be evolved from reptilian ancestors.
- Evolutionary history of birds is very interesting.
- In **1861** from the rocks of Jurassic period, fossil of a bird was found which was given the name of
- Archaeopteryx, the lizard tailed bird.
- A long, tapering lizard like tail consists of **20** caudal vertebrae.
- Nine to ten cervical vertebrae.

# CLASSIFICATION OF MAMMALS

- Mammals are classified into three subclasses:




## SUB-CLASS PROTOTHERIA- THE MONOTREMES

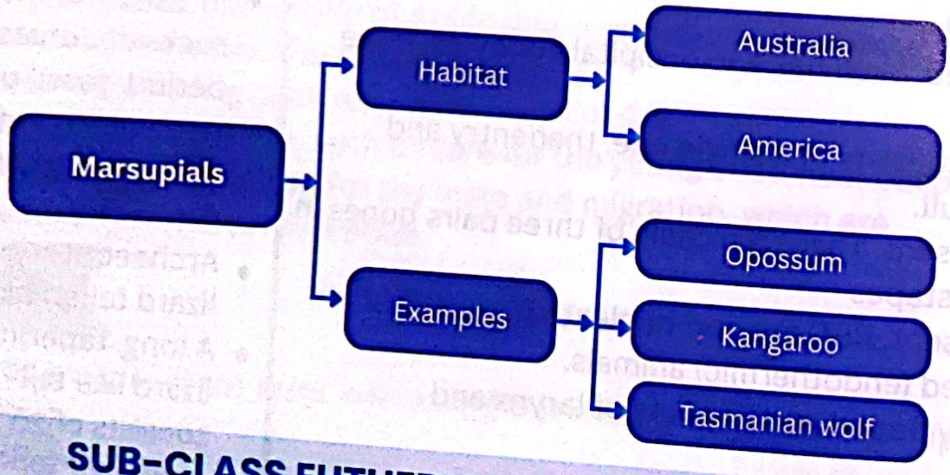
- It is a connecting link between reptiles and mammals and provides evidence of evolution and origin of mammals from reptiles.
- Certain members of this sub-class are adapted for aquatic life e.g. Duck bill platypus, which has a bill like that of a duck and has a webbed toe.
- The mammalian feature of the monotremes is that the female has mammary glands, and they feed their youngs.
- The reptilian features include the presence of cloaca and cloacal opening (instead of separate opening for digestive and urinogenital system).
- Monotremes are found in Australia.
- The examples of monotremes are Duckbill platypus and Echidna-spiny anteater. (Trachyglossus)

## SUB CLASS METATHERIA- THE MARSUPIALS



- The females have an abdominal pouch the marsupium, where they rear their young.
- The young when borne are immature. The nipples are in the pouch.
- The mother feeds the young ones and carries them in the pouch till they are matured enough.






## SUB-CLASS EUTHERIA- THE PLACENTALIS

- Development of young one takes place inside the body of the mother.

- No fusion of ... and sacral vertebrae
- Sternum ... in Archaeop...
- Free cervical ... abdominal ... also present
- Simple brain ... cylindrical ... hemisphere ... unexpanded cerebellum.
- Fore limbs with three clawed fingers.
- The above evid... prove that archaeopteryx ... a connecting li... between reptile... and birds
- Blood is red due ... haemoglobin contained in ova... nucleated RBCs.
- Vocal cords are ... present in larynx but a special sou... box syrinx is present
- Eyes are provided with a third eyelid the nictitating membrane which can be drawn across the eye.
- A rudimentary pinna is present outside the extern... auditory opening
- Ureters open in common cloaca sexual dimorphism is found in many birds.

- The young are borne fully developed. Developing placental mammals are dependent on placenta an organ of exchange between maternal blood and fetal blood.
- Nutrients are supplied to the growing offspring, and wastes are passed to the mother for excretion.
- The young ones are born at a relatively advanced stage of development.
- So, these mammals are called placental mammals. All the placental mammals have maximum mammalian characteristics.
- In some hairs have been modified into scales in pangolin, and spines in porcupine.
- Examples of the placentalis are man, whale, elephant, horse, rat, mice, bat, dolphin, cat, tiger, lion, monkey, gorilla etc.

**FTB**

- Mammals have deciduous and permanent teeth. In some mammals for example in man there are two sets, one in early life the milk teeth and later the permanent teeth.
- Heart is four chambered

# EVOLUTIONARY ADAPTATIONS OF MAMMALS

- A regulated body temperature. This makes them independent of environmental change, keeping active throughout the year, whereas reptiles must hibernate during much of the year.
- An insulating coat of hair that aids in regulating body temperature.
- Complete separation of venous and arterial blood in the heart.
- More efficient mechanism of respiration due to the presence of a diaphragm.
- An active life and a high rate of metabolism. A better developed larynx.
- A separate respiratory passage that avoids interference in breathing during feeding.
- Better developed senses of smell, sight and hearing.
- A more highly developed nervous system.
- Large cerebrum and cerebellum provide for better coordination in all activities and for learning and retentive memory.
- Patterns of behaviour, such as care and nursing of the young, in most of these features the mammals resemble the birds.

**PTB**

- The term mammal was given by Linnaeus to the group of animals
- which are nourished by milk from the breast of the mother.
- The group is considered to be the highest in the animal kingdom. Their advancement over other groups is quite pronounced.
- The most important advancement is the evolution and development of their brain (nervous system) over the other vertebrates.
- It is universally accepted by biologists that mammals have evolved from reptilian ancestors, the **cotylosaurs**.

**BTB**

- Sweat and sebaceous (oil)
- gland is also present.
- Non nucleated red blood cells **except camels.**
- Testes mostly extra abdominal and urinogenital opening and anus is separated.
- Shrews have so little body fat that they cannot go more than a couple of hours without food.
- Missing a meal is a sure way to a quick death. A good night's sleep could be fatal.
- A female Pacific **Grey Whale** gestates and delivers a **2000-pound baby,** migrates over **10,000 miles**, and produces **6 tons** of breast milk without eating a bite of food using just her blubber for fuel.

**KPK**

- Stapes are the smallest bones of the body.
- Testes of male mammals lie in scrotal sac outside the body.

Embryo is kept inside the body of

- This has been determined on the basis of the fossil record which is easily available because of the hard bones that were preserved as fossils, unlike the birds which have soft bones and mostly have not been preserved.
- The ancestors of mammals lived simultaneously along with reptiles during the Jurassic times and have been called mammal-like reptiles. Some were only of the size of mice and lived on trees.
- One of these early reptiles was **varanope** that was found as fossil in Texas.
- Probably at least five groups of such mammal-like reptiles developed mammalian characters and were **50% mammals**.
- **Mammals became dominant in the Cenozoic period.**
- The Metatheria are the most primitive mammals
- Also, the placenta has endocrine function i.e. it produces certain hormones, for this reason these mammals are also called placental mammals.
- Placental mammals have maximum mammalian characters but in some the hair have become modified into scales (pangolin) and spines (porcupine).
- Examples are man, whale, elephant, horse, rat, mice, bat, dolphin, etc.
- Mammals being a very successful group live in all kinds of habitat i.e. land, fresh water and sea for which their bodies are modified.

- process is called **gestation.**
- Marsupials are confined to Australian region with the exception of only Koala etc.
- Eutheria are divided into **sixteen orders**. Some important orders with examples are mentioned below:
- 1. **Insectivora:** Feed on insects, includes moles and shrews.
  2. **Chiroptera:** Flying mammals like bats, flying squirrels.
  3. **Cetacea:** Aquatic mammals e.g. whale, dolphin, porpoises, sea lion etc.
  4. **Carnivora:** Flesh eating like dog, cat, lion. Wolves
  5. **Rodentia:** Cutting habit like rats, mice, squirrel, beavers etc.
  6. **Edentata:** Adults with no or poorly developed molar teeth like South American anteater, sloths.
  7. **Pholidota:** Body covered with large, overlapping, horney scales e.g.
  8. **Pengulin Proboscidea:** Have a long trunk like elephant.
  9. **Perissodactyla:** Odd-toed hoofed

- 11. **Artiodactyla**: Even-toed hoofed
- mammals like cow, goat, deer etc.
  12. **Primates**: Mammals withy highest brain development like lemur, monkeys, apes, tarsiers, human beings etc.
- **Markhor is the national animal of Pakistan.**
- Coelom consists of three portions.
- A **dorsal heart** having invertebrate like blood vessel.
- **Epidermal nervous system.**
- These are either **unisexual** or **bisexual.**
- Indirect development.
- They **feed on micro living thing.**

# BIOENERGETICS

## Introduction

- "Bioenergetics is the **quantitative study of energy relationships and energy conversions** in biological systems"
- Biological energy transformation obeys the laws of
- **thermodynamics.**
- ATP is a kind of chemical link between catabolism and anabolism.
- **ATP → ADP + $P_i$** (catabolic reaction or exergonic reaction)
- **ADP + $P_i$ → ATP** (anabolic reaction or endergonic reaction)

**FTB**

- Sunlight is the ultimate source of energy
- All organisms need free energy for keeping themselves alive and functioning.
- All life on Earth is powered, directly or indirectly, by solar energy.
- However, no organism can directly use sunlight as a source of energy for metabolism; instead, they utilize chemical energy stored in food, such as sugars.
- The chloroplasts of plants capture light energy from the sun and convert it into chemical energy, which is stored in sugars and other organic molecules.

**KPK**

- Shorter wavelengths are more energetic (ultraviolet etc and longer wavelengths like infrared are less energetic.
- About **40%** of the total sunlight that enters atmosphere reaches the earth surface.

## EVOLUTION OF RESPIRATION

- With the emergence of photosynthesis on earth, molecular oxygen
- began to accumulate slowly in the atmosphere.
- The presence of free oxygen made possible the evolution of respiration.
- Respiration releases a great deal of energy, and couples some of this energy to the formation of adenosine triphosphate (ATP) molecules.

## PHOTOSYNTHESIS VERSUS RESPIRATION

The processes of photosynthesis and respiration help in understanding the principles of bioenergetics. They are opposite to each other.

### PHOTOSYNTHESIS

- Photosynthetic organisms (higher land plants for instance) use solar energy to synthesize organic compounds (such as carbohydrates)
- It is an **anabolic reaction** (energy capturing)
- It needs the input of energy.
- It requires sunlight to start the process.
- Occurs only during daytime.
- $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

### RESPIRATION

- Organisms break organic food to get energy for the cellular processes
- It is **catabolic reaction** (energy releasing)
- It releases the energy of food (ATP)

- It is independent of light.
- Occurs day and night.
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

# PHOTOSYNTHESIS

- Photosynthesis can be defined as the process in which energy-poor inorganic oxidised compounds of carbon (i.e. $CO_2$) and hydrogen (i.e. mainly water) are reduced to energy-rich carbohydrate (i.e. sugar-glucose) using the light energy that is absorbed and converted into chemical energy by chlorophyll and some other photosynthetic pigments.

## OCCURRENCE

- It occurs in plants, algae, cyanobacteria and photosynthetic bacteria.
- From above overall reaction of photosynthesis, it becomes evident that carbon dioxide, water and light is the reactant while glucose and oxygen are the products.
- Water appears on both sides of the equation because water is used as reactant in some reactions and released as product in other.
- However, because there is no net yield of $H_2O$, we can simplify the summary equation of photosynthesis for purpose of discussion:

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

PTB

## COMPENSATION POINT

- At **dawn and dusk**, when light intensity is low, the **rate of photosynthesis and respiration** may, for a short time, equal one another.
- Thus, the oxygen released from photosynthesis is just the amount required for cellular respiration.
- Also, the carbon dioxide released by respiration just equals the quantity required by photosynthesizing cells.
- At this moment there is **no net gas exchange** between the leaves and the atmosphere.
- This is termed as compensation point.
- As the light intensity increases, so does the rate of photosynthesis and hence the requirement for more carbon dioxide increases which respiration alone cannot supply.
- Similarly, the oxygen produced during photosynthesis is more than the need of the respiring cells, so the result is the net release of oxygen coupled with the uptake of carbon dioxide.



## ROLE OF WATER IN PHOTOSYNTHESIS

- In **1930s**, Van Neil hypothesized that plants split water as a source of hydrogen, releasing oxygen as a by-product.
- Neil's hypothesis was based on his investigations on photosynthesis in bacteria that make carbohydrate from carbon dioxide, but do not release oxygen.
- Neil's hypothesis that **source of oxygen released during photosynthesis** is water and not carbon dioxide, was later confirmed

- by scientists during **1940s** when first use of an isotopic tracer ($O^{18}$) in biological research was made.
- Water and carbon dioxide containing heavy-oxygen isotope $O^{18}$ were prepared in the laboratory.
- Experimental green plants in **one group** were supplied with **H2O containing $O^{18}$** and with $O_2$ containing only common oxygen $O^{16}$.
- Plants in the **second group** were supplied with **H2O containing common oxygen $O^{16}$** but with $CO_2$ containing $O^{18}$.
- It was found that plants of the first group produced $O^{16}$, but the plants of second group did not.

**Experiment #1**

$$6CO_2 + H_2O^{18} \rightarrow C_6H_{12}O_6 + 6H_2O + {}_6O_2^{18}$$

**Experiment #2**

$$6CO_2^{18} + 12H_2O \rightarrow C_6H_{12}O_6^{18} + 6H_2O^{18} + 6O_2$$

Water is thus one of the raw materials of photosynthesis, other being carbon dioxide

**PTB**

- Oxygen released during photosynthesis comes from water and is an important source of atmospheric oxygen which most organisms need for aerobic respiration and thus for obtaining energy to live.
- Hydrogen produced by splitting of water reduces NADP to $NADPH_2$ ($NADPH + H^+$).
- **NADPH** is the **"reducing power"** which, along with ATP also formed during 'light reactions', is used to reduce $CO_2$ to form sugar during 'dark reactions.



**FTB**

- Water acts as a hydrogen and electron donor in photosynthesis.
- It replaces the electron lost by P680 during photosynthesis.
- $2H^+$ ions taken up by the $NADP^+$ to form NADPH.

## ROLE OF LIGHT IN PHOTOSYNTHESIS

- Light is a form of energy is called **electromagnetic energy or radiation.**
- The full range of **electromagnetic radiation** in the universe is called electromagnetic spectrum.
- **Pigments** are the substances that absorb **visible light (380nm-750nm in wavelength)**
- Different pigments absorb light of different wavelengths, and the wavelength that are absorbed disappear
- Leaves absorb only **1%** of the total light which fall in them rest is reflected or transmitted.
- An instrument called a spectrophotometer is used to measure relative abilities of different pigments to absorb different wavelengths of light

## ROLE OF PHOTOSYNTHETIC PIGMENTS

- A photosynthetic pigment is a pigment that is present in chloroplasts or photosynthetic bacteria and captures the light energy necessary for photosynthesis.
- All the pigments that take part in photosynthesis are embedded in thylakoid membranes (grana lamella) within chloroplasts.

PTB

- Thylakoid membranes contain several kinds of pigments, but chlorophylls are the main photosynthetic pigments.
- Other, accessory photosynthetic pigments present in the chloroplasts include yellow and red to orange carotenoids; carotenes are mostly red to orange and xanthophylls are yellow to orange.
  These broaden the absorption and utilization of light energy.

FTB

- A particular pigment shows only those wavelengths which are reflected back.
  Higher plants have two major group of pigments i.e., chlorophyll and carotenoids

## CHLOROPHYLL

- Chlorophylls are **green and main photosynthetic pigments** which **absorb violet-blue and orange red wavelengths**, while **green, yellow and indigo** are least absorbed and are reflected or transmitted. Therefore, leaves look green.
- There are **six types of chlorophylls** (a,b,c,d,e,f) and out of these only two types occur in chloroplasts of higher plants i.e., chlorophyll a and b
- Chlorophyll c and d are found in algae while chlorophyll e and f are found only in bacteria.
- The photosynthetic bacteria have **bacteriochlorophylls ($C_{55}H_{74}O_6N_4Mg$).**

PTB

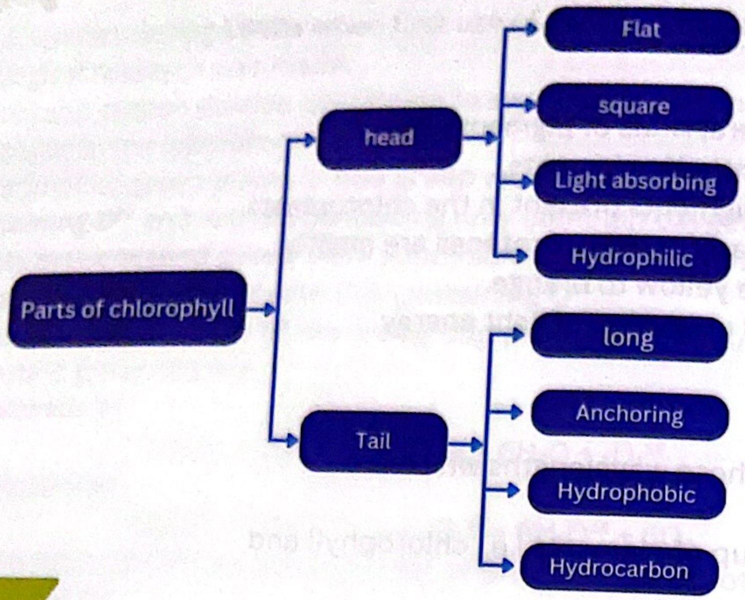
- Chlorophylls are insoluble in water but soluble in organic solvents, such as carbon tetrachloride, alcohol



## STRUCTURE OF CHLOROPHYLL

### HEAD

- The head is **complex porphyrin ring** which is made up of **4** joined **smaller pyrrole rings** (each pyrrole ring is composed of **4** carbon and **1** nitrogen atom)
- An atom of magnesium is present in the centre of porphyrin ring and is coordinated with the nitrogen of each pyrrole ring.




**BTB**

- Chlorophyll a molecule is also called universal pigment.

**KPK**

- Photosynthetic bacteria lack chloroplasts, but they do have unstacked photosynthetic membranes.
- These membranes work like thylakoid membrane.
- Chlorophyll is attached to these membranes

**PTB**

- That is why magnesium deficiency causes yellowing in plants.
- Haem portion of haemoglobin is also a porphyrin ring but containing an iron atom instead of magnesium atom in the centre.

**FTB**

- Pyrrole group also contains different groups around them.
- It is exposed on the surface of thylakoid membranes.
- It is light absorbing part of chlorophyll.

## TAIL

- Long hydrocarbon tail which is attached to one of the pyrrole rings is phytol ($C_{20}H_{39}$).
- The chlorophyll molecule is embedded in the hydrophobic core of thylakoid membrane by this tail.



**FTB**

- There are **two side chains** in chlorophyll molecule called as tails. Side chains are **phytol** and **methyl ester**.
- Tail serves to anchor the chlorophyll molecules in the thylakoid membranes

## CHLOROPHYLL A

- It is **blue green** in colour
- It is a universal photosynthetic pigment found in all photosynthetic organisms except photosynthetic bacteria.

**PTB**

- Of all the chlorophylls, chlorophyll a is the-most abundant and the most important photosynthetic pigment as it takes part directly in the light-dependent reactions which convert solar energy into chemical energy.

## CHLOROPHYLL B

- It is yellow green in colour
- It occurs in all photosynthetic organisms except red, brown algae and photosynthetic bacteria.

## DIFFERENCE BETWEEN CHLOROPHYLL A AND B

| Feature | Chlorophyll a | Chlorophyll b |
|---|---|---|
| Molecular formula | $C_{55}H_{72}O_5N_4Mg$ | $C_{55}H_{70}O_6N_4Mg$ |
| Occurrence | All photosynthetic organisms except bacteria. | All green plants and green algae |
| Functional group | $CH_3$ (methyl group) bonded to 2nd pyrrole ring. | CHO (formyl group) is bonded to 2nd pyrrole ring |
| Forms | Differ in their red absorbing peaks e.g.,670, 680,690,700 | No such different forms. |
| Colour | Blue green | Yellow green |
| Pigment | Primary pigment | Accessory pigment |

**PTB**

- Due to this slight difference in their structure, the two chlorophylls show slightly different absorption spectra and hence different colours.
- Some wave lengths not absorbed by chlorophyll a are very effectively absorbed by chlorophyll b and vice-versa.
- Such differences in structure of different pigments increase the range of wave lengths of the light absorbed.

## CAROTENOIDS

- Carotenoids are **yellow, brown and red to orange pigments** that absorb strongly the blue-violet range, different wave lengths than the chlorophyll absorbs.
- These and chlorophyll b are called **accessory pigments** because they absorb light and transfer the energy to chlorophyll a, which then initiates the light reactions.
- Some carotenoids protect chlorophyll from intense light by absorbing and dissipating excessive light energy, rather than transferring energy to chlorophyll.

**PTB**

- So, they broaden the spectrum of light that.
- Provides energy for photosynthesis.
- It is generally believed that the order of transfer of energy is:

**Carotenoids → chlorophyll b → Chlorophyll a**

- Carotenoids may be protecting human eyes.

**BTB**

- Acid chain: it is methyl ester chain.
- Hydrocarbon tail: it is an alcohol phytol. ($C_{20}H_{39}$)
- It is an ester linkage with propionic acid.
- Phytol consists of four isoprene units.

**BTB**

- Carotenoids also protect chlorophyll from oxidation by oxygen produced in photosynthesis.
- Carotene has general formula $C_{40}H_{56}$.
- Red colour of tomato and chilli are due to carotenes.
- Beta carotene is converted to Vitamin A by animals and human beings.
- **Xanthophylls** are oxygen containing derivatives of carotene ($C_{40}H_{56}O_2$)
- Lutein and

**FTB**

- These are terpenoids lipids
- They are seen in leaves before leaf fall, present in some flowers and fruits

Carotenoids
Carotenes | Xanthophylls

- The carotenes are orange red pigments, composed of isoprenoid units and are found in all photosynthetic eukaryotes.
- The most widespread and important carotene is β (beta) carotene.
- Xanthophylls are yellow in colour and are also composed of isoprenoid units.
- Lutein is widely distributed xanthophylls which is responsible for yellow colour of foliage in autumn, attract insects, birds and other animals for pollination and dispersal.

## ACTION SPECTRUM

- "Such a graph which shows the **effectiveness of different wavelength of light** for the process of photosynthesis is called action spectrum."
- Analysis of action spectrum indicates that blue (**430nm**) and red (**670nm**) wavelengths of light are the most effective for the process of photosynthesis.
- The effectiveness of a particular wavelength of light for the process of photosynthesis primarily depends upon its absorption in the plant body.
- As different wavelengths (colours) of visible light are differently absorbed by various photosynthetic pigments, therefore, each wavelength has its own effectiveness for the process of photosynthesis.
- If a plant is illuminated in different colours of light one by one, the rate of photosynthesis is measured and the data obtained in this way is plotted in a graph, you will see that the rate of photosynthesis will be variable in different colours of light.



**PTB**

- The first action spectrum was obtained by German biologist T.W. Engelmann in **1883** he worked on Spirogyra (algae)
- In action spectrum peaks are broader
- Valleys are not deep
- Action spectrum can be obtained by illuminating plant with light of different wavelength and then estimating relative $CO_2$ consumption or oxygen released during photosynthesis
- The action spectrum of photosynthesis corresponds to absorption spectrum of chlorophyll the same two peaks and the valley are obtained for absorption of light as well as for $CO_2$ consumption.
- This also shows that the chlorophyll is a photosynthetic pigment

and zeaxanthin are the two primary xanthophylls found in green leafy vegetables and other foods like eggs.

- The xanthophylls of brown algae is called fucoxanthin $(C_{40}H_{56}O_2)$
- Both carotenes and Xanthophylls are lipid compounds, soluble in organic solvents like other lipids.

**BTB**

- As photosynthesis produces oxygen and consumes $CO_2$, the rate of production of oxygen or consumption of $CO_2$ can be used as a measure of the rate of photosynthesis.
- Whole amount of energy is not stored in organic compounds.
- Some of it released as heat and the rest is stored in organic compounds as chemical energy.

**BTB**

- Chlorophyll a shows peaks at about **680 and 700 nm.**
- Chlorophyll b absorption peaks range between **450-475 nm.**

- The action spectrum of photosynthesis does now parallel the absorption spectrum of chlorophyll exactly.
- When equal intensities of lights are given, there is more photosynthesis in red than in blue part of spectrum.
- Photosynthesis in 500-600 nm (including green light) is more than the absorption of green light by chlorophyll.

KPK

To measure the absorption of a pigment, a pure solution of the extracted pigment is obtained.

## ABSORPTION SPECTRUM

"Such a graph which shows the absorption of different colours of light by a particular pigment is called absorption spectrum of pigment."

PTB

- Absorption spectrum for chlorophyll indicates that absorption is maximum in blue and red parts of the spectrum, **2 absorption peaks** being at around **430 nm** and **670 nm** respectively.
- Absorption peaks of carotenoids are different from those of chlorophyll
- Peaks of wavelength absorbed are narrow
- In this case valley is deep.

FTB

- The absorption spectra of different pigments indicate that that they absorb different wavelengths of visible light, and these wavelengths are not absorbed at the same rate.
- Photoreceptors are chlorophyll a and b, and both show more absorption in violet blue **(400nm to 470nm)** and orange red **(630nm to 660nm)** regions of the visible spectrum.
- On the other hand, carotenoids show more absorption at **430nm to 500nm.**



| Action Spectrum | Absorption Spectrum |
|---|---|
| It is the graph showing the rate of photosynthesis at each wavelength, plotted by estimating relative $CO_2$ consumption or oxygen release during photosynthesis. | It is the graph showing wavelengths of light absorbed by a pigment. |
| It does not parallel the absorption spectrum of chlorophyll exactly. It is more than absorption of different wavelengths due to the presence of accessory pigments. | The sum of the absorption spectra corresponds to the action spectrum of photosynthesis. |
| Peaks are broader. | Peaks of wavelengths absorbed are narrow. |
| Valley is not deep. | Valley is deep. |

## PHOTOSYNTHESIS

- It is not a simple, single step process, but is a complex one that is completed by a series of simple steps or reactions. These reactions of photosynthesis consist of two parts:
- The **light-dependent reactions** (light reactions) which use light directly and
- The **light-independent reactions** (dark reactions) which do not use light directly

## LIGHT REACTIONS

- Light dependent reactions constitute that phase of photosynthesis during which light energy is Absorbed by chlorophyll and other photosynthetic pigment molecules and converted into chemical Energy.
- As a result of this energy conversion, reducing and assimilating power in the form of **NADPH (NADPH + $H^+$) and ATP**, are formed, both temporarily storing energy to be carried along with H to the light independent reactions.
- Light reaction takes place in the grana of chloroplast.

## DARK REACTIONS

- The products of light reactions, NADPH provides energized electron (and $H^+$), while ATP provides chemical energy for the synthesis of sugar by reducing **$CO_2$,** using reducing power and chemical energy of NADPH and ATP respectively, produced by light reactions.
- The energy is thus stored in the molecules of sugar.
- This phase of photosynthesis is also called dark reactions because these reactions do not use light directly and can take place equally well both in light and dark provided $NADPH_2$ and ATP of light reactions are available.
- Dark reaction takes place in the **stroma of chloroplast**.

## ARRANGEMENT OF PIGMENTS (PHOTOSYSTEM)

- Photosynthetic pigments are organized into clusters, called photosystems, for efficient absorption and utilization of solar energy in thylakoid membranes

## COMPONENTS OF PHOTOSYSTEMS

- Each photosystem consists of a light gathering antenna complex and a reaction centre.

### ANTENNA COMPLEX



- The antenna complex has many molecules of chlorophyll a, chlorophyll b and carotenoids, most of them channelling the energy to reaction centre.

**FTB**

- It is the peripheral part of photosystem.

### REACTION CENTRE

- Reaction centre has one or more molecules of chlorophyll a along with a primary electron acceptor, and associated electron carriers of 'electron transport system'.

**PTB**

- Chlorophyll a molecules of reaction centre and associated proteins

are closely linked to the nearby electron transport system.
Primary electron acceptor traps the high energy electrons from the reaction centre and then passes them on to the series of electron carriers. During this energy is used to generate ATP.

FTB

- It is the central part of photosystem.
- It also contains associated proteins which are responsible for deviation of spectrum of PS-1 and PS-2.

The light is absorbed by the pigment molecules and then transferred from one molecule to other and finally reaches the reaction centre where this light energy is converted into the chemical energy.

## ELECTRON TRANSPORT SYSTEM

- Electron transport system plays role in generation of ATP by chemiosmosis.
- Light energy absorbed by the pigment molecules of antenna complex is transferred ultimately to the reaction centre.
- There the light energy is converted into chemical energy.
- Electron transport system plays role in generation of ATP by chemiosmosis.
- Light energy absorbed by the pigment molecules of antenna complex is transferred ultimately to the reaction centre.
- There the light energy is converted into chemical energy.

## TYPES OF PHOTOSYSTEMS

- Since chlorophyll a generally has an optimal absorption wavelength of **660nm**, it associates with different proteins in each type of photosystems to slightly shift its optimal wavelength producing two distinct photosystem types i.e., photosystem-I (PS-I), photosystem-II (PS-II)
- These photosystems are named according to their order of discovery

BTB

Primary electron acceptor in PS-II is called pheophytin.



| PS-I | PS-II |
|---|---|
| It is located mainly in non-stacked thylakoids. | It is present in stacked membranes of grana. |
| It is found in plants, algae, cyanobacteria, and photosynthetic bacteria. | It is absent in photosynthetic bacteria. |
| It contains chlorophyll a and accessory pigments (chlorophyll b and carotenoids). | It contains chlorophyll a and accessory pigments (chlorophyll b and carotenoids). |
| It strongly absorbs light of about 700 nm; hence, it is called $P_{700}$. | It strongly absorbs light of about 680 nm; hence, it is called $P_{680}$. |

- The stomata cover over only **1-2%** leaf surface.
- Air contains about **0.03-0.04%** of $CO_2$.
- This $CO_2$ is used by terrestrial plants while aquatic plants use $CO_2$ dissolved in water as carbonates.

## LIGHT REACTIONS

- Light dependent phase of photosynthesis involves the **absorption of light by the photosystems, excitation and flow of electrons** through an electron transport chain chemiosmotic synthesis of

ATP, and reduction of NADP to NADPH.

- The flow of excited electrons through an electron transport chain during light reaction is of two different types
- **Non-cyclic phosphorylation**
- **Cyclic phosphorylation**
- This production of ATP during light reaction is called photophosphorylation and the mechanism is called chemiosmosis.
- Photosystem-I can absorb maximum wavelength of **700nm** while photosystem-II can absorb **680 nm**.

# NON-CYCLIC PHOTOPHOSPHORYLATION.

- In non-cyclic electron flow, the excited electrons after leaving a particular photosystem do not comeback, these electrons after losing their energy are incorporated into another molecule.
- The events of non-cyclic photophosphorylation are continuous but here they are discussed in steps for convenience:

## ABSORPTION OF LIGHT BY PS-II AND EXCITATION OF ITS ELECTRONS

- When just two photons strike the antenna complex of PS-II, the two electrons become excited and begin to move along the atoms of different pigments within photosystem.
- Each photon excites one electron.
- Ultimately, the absorbed energy reaches the reaction centre of PS-II **(P680)** and causes its two electrons to be excited.
- These excited electrons are captured by the primary electron acceptor of PS-II and leave two "electron holes in the photosystem behind making chlorophyll a strong oxidizing agent.

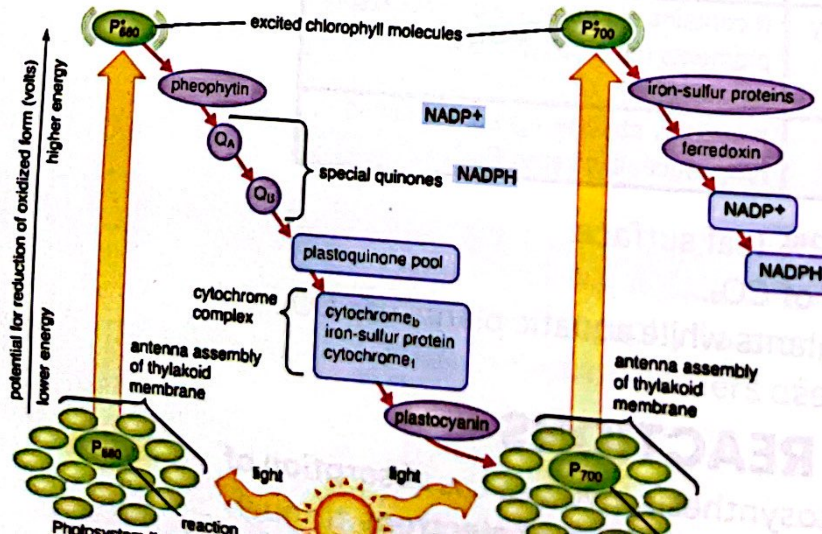


## PHOTOLYSIS OF WATER

- The electron holes of photosystem must be filled so that in the presence of water splitting enzyme reactions can proceed.
- When water reacts with oxidized state of chlorophyll in photosystem, it breaks up into $2H^+$ ions, $2e^-$ and $\frac{1}{2}O_2$.
- Since this breakdown occurs in the presence of sunlight therefore, it is termed as photolysis of water.
- The electrons released from water are used to fill the "electron holes".



$$H_2O \rightarrow 2H^+ + 2e^- + \frac{1}{2}O_2$$



PTB

The oxygen produce during photolysis is the main source of replenishment of atmospheric oxygen

## ELECTRON FLOW FROM PS-II TO PS-I

- Each photo excited electron passes from the primary electron acceptor of photosystem II to photosystem I via an electron transport chain.
- This chain consists of an electron carrier called plastoquinone (Pq), a complex of two cytochromes.

FTB

The two cytochromes are **cyt-b6** and **cyt-f**

## PHOTOPHOSPHORYLATION

- As electrons move down the chain, their energy goes on decreasing and is used by thylakoid membrane to produce ATP.
- This ATP synthesis is called photophosphorylation because it is driven by light energy.
- Specially, ATP synthesis during non-cyclic electron low is called non-cyclic photophosphorylation.
- This ATP generated by the light reactions will provide chemical energy for the synthesis of sugar during the Calvin cycle, the second major stage of photosynthesis.

## • ABSORPTION OF LIGHT BY PS-I AND EXCITATION OF ITS ELECTRONS



- On the other hand, when **P700** in the reaction centre of **PS-I** molecule absorbs two photon of light, electrons are boosted to a higher energy level.
- **P700** molecule passes these excited electrons to a primary electron acceptor of **PS-1**, creating "electron holes":
- The electron holes of **P700** are filled by the pair of electrons received from the **P680** (photosystem II) via electron transport chain.

## ELECTRON FLOW FROM PS-I TO NADP+

- The primary electron acceptor of photosystem- I passes the photo excited electrons to a second electron transport chain.
- The electrons are accepted by ferredoxin (Fd). It is an iron containing protein.
- An enzyme called NADP reductase Transfers the electrons from Fd to $NADP^+$.
- $NADP^+$ combines with electrons and hydrogen ions to form NADPH (reduced).
- The NADPH will provide reducing power for the synthesis of sugar in the Calvin cycle.

PTB

This is a redox reaction that stores the high energy electrons in

NADPH

**FTB**

NADP reductase is a flavoprotein enzyme.

$$NADP^+ + 2e^- + 2H^+ \rightarrow NADPH + H^+$$

## Z-SCHEME

- The path of electron transport through the two photosystems during non-cyclic photophosphorylation is known as Z-Scheme due to its conceptual zig-zag shape

# CYCLIC PHOTOPHOSPHORYLATION

- In the cyclic photophosphorylation the excited electrons after leaving a particular photosystem finally come back to their photosystem again.

## EXPLANATION

- Under certain conditions, photo excited electrons take an alternative path called cyclic electron flow.
- This path uses photosystem I but not photosystem II.
- Possibly, it appears when the chloroplast runs low on ATP for the Calvin cycle, the cycle slows down and NADPH accumulates in the chloroplast.
- This rise in NADPH may temporary shift from non-cyclic to cyclic electron flow until ATP supply meets the demand.
- The cyclic flow is short circuit: The electrons cycle back from primary electron acceptor to ferredoxin (Fd) to the cytochrome complex and from there continue on to the **P700** chlorophyll.
- ATP is generated by the coupling of ETC by chemiosmosis.
- There is no production of NADPH and no release of oxygen and no photolysis of water.
- Cyclic flow does, however, generate ATP. This is called cyclic photophosphorylation.



**FTB**

- It absorbs energy in the form of photons

| Non-cyclic phosphorylation | Cyclic phosphorylation |
|---|---|
| 1. Electrons do not come back to the same molecule. | Electrons come back to the same molecule. |
| 2. First electron donor is water | First electron donor is P700 (PS-I) |
| 3. Involves both PS-I and PS-II | Involves PS-1 only |
| 4. Last electron acceptor is NADP. | Last electron acceptor is P700. |
| 5. The net products are ATP, NADP, $O_2$ | The product is ATP only. |
| 6. More common | Less common |

FTB

- It is also called EMP pathway because it was discovered by three German scientists Embden, Meyerhof and Parnas

# PHASES OF GLYCOLYSIS

- It can be divided into two phases

## PREPARATORY PHASE

- In this phase **energy is expended.**
- Two ATPs are consumed, and its final products are two molecules of G3P.

## OXIDATIVE PAY-OFF PHASE

- It is an energy yielding phase in which not only ATPs are produced (high energy phosphate bonds are formed, and energy is stored) through substrate level phosphorylation, but it also produces NADH which upon further oxidation in respiratory electron transport chain yields more ATPs.

# STEPS OF GLYCOLYSIS

- Glycolysis is completed in following steps:

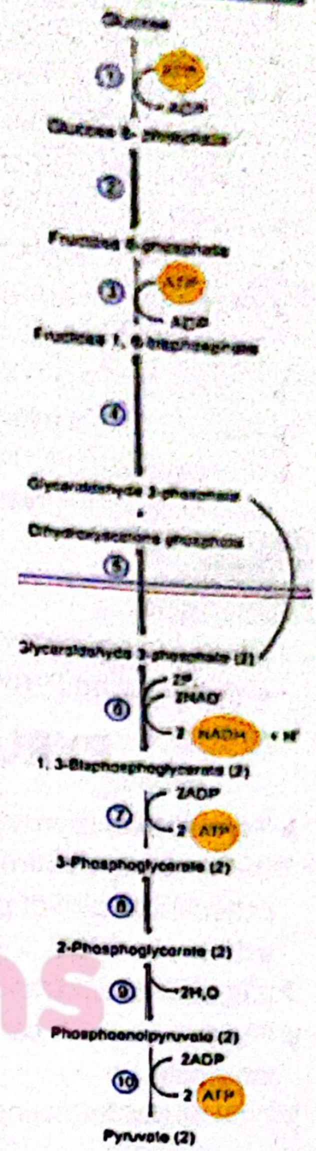
## PREPARATORY PHASE (ENERGY INVESTMENT PHASE)

- The first step in glycolysis is the transfer of a phosphate group from ATP To glucose. As a result, a molecule of glucose-6 -phosphate is formed.
- An enzyme catalyses the conversion of glucose-6-phosphate to its isomer, fructose-6-phosphate.
- At this stage another ATP molecule transfers a second phosphate group. The product is fructose 1,6-bisphosphate.
- The Next step in glycolysis is the enzymatic splitting of fructose 1,6 - bisphosphate into two fragments. Each of these molecules contains three carbon atoms. One is called 3 – phospo- glyceraldehyde, 3-PGAL or Glyceraldehyde 3-phosphate (G3P) while the other is dihydroxyacetone phosphate.
- These two molecules are isomers and in fact, are readily interconverted by yet another enzyme of glycolysis.
- Next phase of glycolysis is proceeded by two molecules of G3P, therefore, the remaining reactions occur twice.

## OXIDATIVE PHASE

- The next step in glycolysis is crucial to this process.
- Two electrons or two hydrogen atoms are removed from the molecule of 3- Phosphoglyceraldehyde (PGAL) and Transferred to a molecule of NAD.
- This is of course, an oxidation-reduction reaction, with the PGAL Being oxidized and the NAD being reduced.
- During this reaction, a second phosphate group is donated to the

SYMPATHETIC NERVOUS SYSTEM




- **Isomerization** occurs 3 times at point number 2,5 and 8 as in the above figure.
- The direct synthesis of ATP from organic phosphorylated substrate is called substrate level **phosphorylation.**

molecule from inorganic phosphate present in the cell.

- The resulting molecule is called 1,3-Bisphosphoglycerate (BPG).
- The oxidation of PGAL is an energy yielding process.
- Thus a "high energy" phosphate bond is created in this molecule.
- At the very next step in glycolysis this phosphate group is transferred to a Molecule of adenosine diphosphate (ADP) converting it into ATP. The end product of this reaction is **3-phospho glycerate (3-PG).**
- In the next step **3-PG** is converted to **2-Phosphoglycerate (2PG).**
- From **2PG** a molecule of water is removed, and the product is phosphoenol pyruvate (PEP).
- PEP then gives up its 'high energy' phosphate to convert a second molecule of ADP to ATP.
- The product is pyruvate, pyruvic acid **($C_3H_4O_3$).**
- It is equivalent to half glucose molecule that has been oxidized to the extent of losing two electrons (as hydrogen atoms).

**BTB**

- Glycolysis does not need free oxygen thus probably first life was **anaerobic bacteria.**
- It is found in all organisms and evolved before the krebs cycle and ETC.
- **1,3-Bisphosphoglycerate (BPG)** is also called as diphosphoglycerate (DPG).

**FTB**

Phosphoenol pyruvate is converted into pyruvate with the help of enzyme called Pyruvate kinase.

## PYRUVIC ACID OXIDATION

- Pyruvic acid (pyruvate), the end product of glycolysis, does not enter the Krebs cycle directly but they undergo an intermediate phase called oxidation of pyruvate or link reaction as it links the glycolysis with Krebs cycle.
- It is also called transition reaction.
- The pyruvate (3- carbon molecule) is first changed into 2-carbon molecule.
- It takes the following three steps.

**KPK**

- 2 ATP are used in preparatory phase and 4 produced in oxidative phase so the net gain of ATP is 2ATPs.

### PYRUVIC ACID OXIDATION

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- It takes the following three steps.

### DECARBOXYLATION

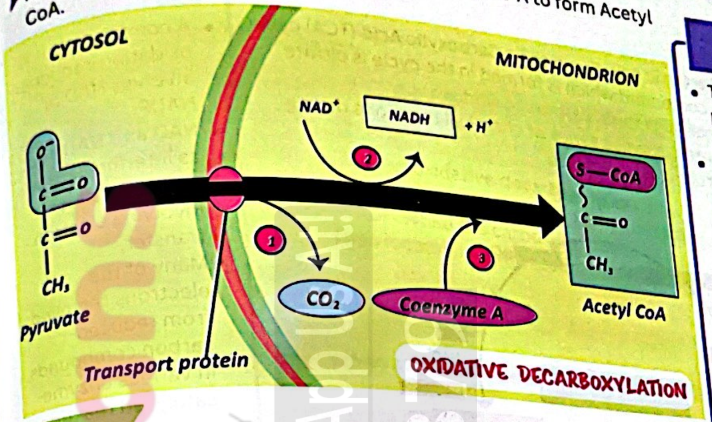
- First, it undergoes decarboxylation in which a molecule of $CO_2$ is removed from pyruvate to form 2 carbon molecule called as acetaldehyde.

### OXIDATION/DEHYDROGENATION

- Then $NAD^+$ removes hydrogen from the acetaldehyde.
- As a result of this oxidation/dehydrogenation a **2-C fragment acetyl** and **NADH** are produced.



- Finally, the acetyl group is combined with coenzyme-A to form Acetyl CoA.




**BTB**

- The oxidation of pyruvic acid takes place in 2 stages.
- **1. Oxidation of pyruvic acid to form Acetyl Coenzyme A**
  - It is an oxidation reaction in which electrons are removed from pyruvate by dehydrogenase that uses NAD as a coenzyme.
  - This reaction occurs twice for each original glucose molecule.

**2Pyruvate + 2CoA → 2 Acetyl CoA + 2CO2**

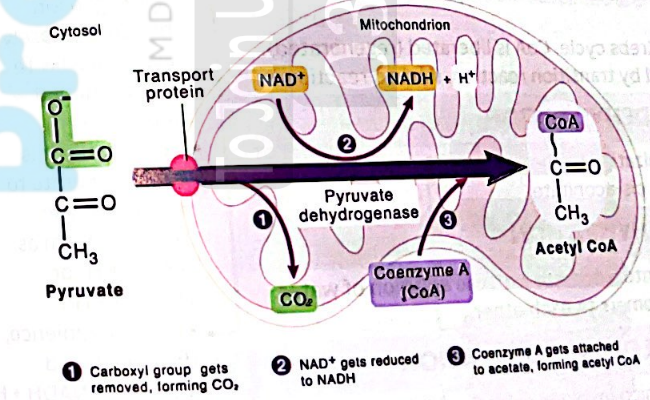
- 2. Oxidation of Acetyl Coenzyme A
  - It takes place through Krebs cycle.

**PTB**

- The pyruvate after removal of $CO_2$ is converted into acetic acid.
- Acetic acid on entering the mitochondrion unites with coenzyme-A (Co A) to form acetyl CoA (active acetate).

**FTB**

- The pyruvate after the removal of $CO_2$ is converted into acetaldehyde. Pyruvates are produced in cytosol.
- Pyruvates are charged molecules it must enter mitochondria via active transport with the help of transport proteins.
- It links the pathway of aerobic respiration that occurs outside the mitochondria with that occurs inside the mitochondria.




**KPK**

- Coenzyme A consists of a nucleotide and a portion of one of the vitamins B.

The Link reactions are as follows:

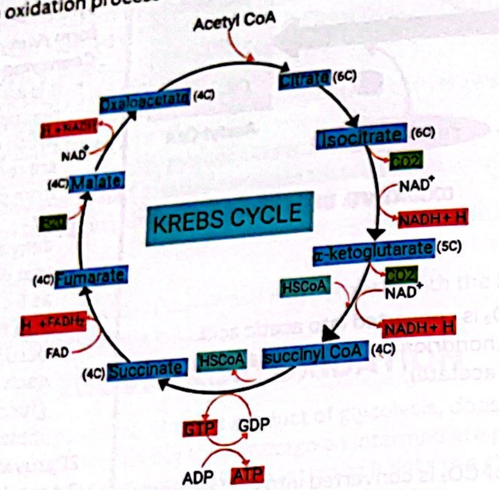
- Pyruvic acid → Acetyl group + $CO_2$ + $2H^+$
- Acetyl group + CoA → Acetyl CoA
- $NAD + 2H^+ \rightarrow NADH_2$

## KREB'S CYCLE

- This cycle was discovered by British Scientist Sir Hans Krebs, therefore called as Krebs cycle.

**FTB**

- It is also called the Citric Acid Cycle or Tri Carboxylic Acid (TCA) cycle because the first compound which is formed in the cycle is citrate (Citric acid) that contains three carboxylic acid groups. Acetyl CoA now enters a cyclic series of chemical reactions during which oxidation process is completed.




## STEPS OF KREB'S CYCLE

- The Krebs cycle involves following nine steps:

### 1. SYNTHESIS

- Acetyl CoA (2-C compound) and a water molecule combines with oxaloacetate (4C compound) to form 6 C compound called citrate (citric acid).
- It is the first product of Krebs cycle. CoA is liberated (regenerated).
- 2C acetyl group is formed by transition reaction. (Linked reaction.)

### 2. DEHYDRATION

- Citrate undergoes reorganization by the removal of water molecule. The resulting compound is cis-aconitate.

### 3. HYDRATION

- Cis-aconitate is converted into isocitrate with the addition of water.
- Citrate and iso citrate are isomers to each other.

### 4. OXIDATIVE DECARBOXYLATION

- This is a two-step process, which involves oxidation/dehydrogenation of isocitrate, followed by the decarboxylation to form Alpha ketoglutarate.
- The hydrogen and electrons which are released from isocitrate are taken up by $NAD^+$ to form NADH while the carboxyl group is released in the form of $CO_2$.

**SCIENCE TIDBITS**

- A complex oxidation-reduction involves NAD or NADP.
- NAD and NADP act as intermediate in cellular reactions involving electron transfer.
- Many of the electrons removed from reduced carbon compounds in various enzyme catalysed reactions are transferred to NAD to produce NADH.
- When a molecule of NAD or NADP gains electrons and becomes reduced, a hydrogen ion combines with it as well.
- Thus, the reduced form is symbolized as NADH or NADPH.
- In fact, another hydrogen ion becomes closely associated with each reduced molecule.
- Technically it is more accurate to represent the reduced form as $NADH + H^+$ or $NADPH + H^+$.
- For convenience, these reduced forms i.e., $NADH + H^+$ and $NADPH + H^+$ can be represented as $NADH_2$ and $NADPH_2$ respectively.





**PTB**

This is $NAD^+$ mediated oxidation.

### 5. OXIDATIVE DECARBOXYLATION AND ADDITION OF CO-A

- Alpha ketoglutarate again undergoes oxidative decarboxylation. The hydrogen and electrons which are released from Alpha ketoglutarate are taken up by NAD to form NADH While the carboxyl group is released in the form of $CO_2$. Then it combines with coenzyme A to form succinyl CoA.

**PTB**

- The product then has one carbon atom and one oxygen atom less. It is succinate.
- The conversion of a-ketoglutarate into succinate is accompanied by a free energy change which is utilized in the synthesis of an ATP molecule.

### 6. FORMATION OF ATP

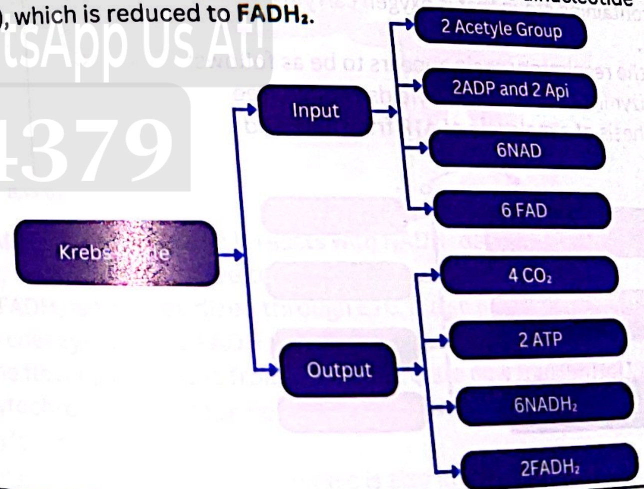
- Coenzyme A is removed from Succinyl CoA to form Succinate.
- The reaction releases sufficient energy which is used to combine GDP and Pi forming GTP.
- GTP reacts with ADP to form ATP while GTP is again converted into GDP.
- In this way a molecule of ATP is generated in this reaction.

### 7. DEHYDROGENATION / OXIDATION

- Succinate undergoes dehydrogenation/oxidation to form fumarate. The hydrogen and electrons which are released from succinate are taken up by FAD to form $FADH_2$.

**PTB**

The oxidizing agent is a coenzyme called flavin adenine dinucleotide (FAD), which is reduced to $FADH_2$.



## 8. HYDRATION

- A molecule of water gets added to fumarate to form malate.

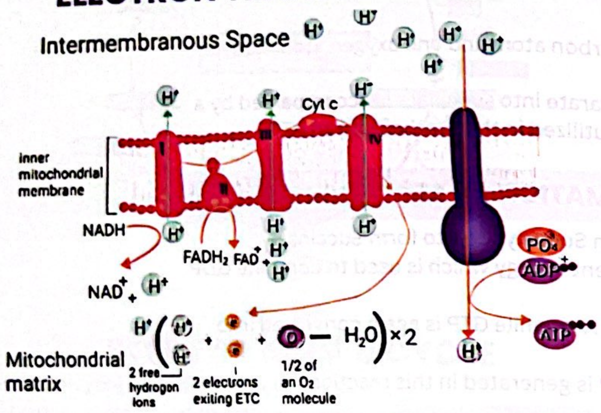
## 9. DEHYDROGENATION / OXIDATION

- Malate undergoes dehydrogenation/oxidation to produce oxaloacetate.
- This is the NAD mediated oxidation of malate
- The hydrogen and electrons which are released from malate are taken up by $NAD^+$ to form NADH.
- The oxaloacetate may now combine with another molecule of acetyl CoA to enter the cycle and the whole process is repeated

**KPK**

- The energy of substrate used in the generation of ATP is called as substrate level phosphorylation.

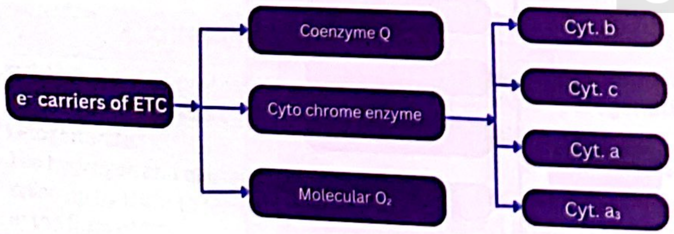
## ELECTRON TRANSPORT CHAIN




**BTB**

- The ETC is located in cristae of mitochondria.
- Each NADH H+ gives **3 ATP** in electron transport, while each FAD gives **2ATP**.
- Electron transport chain is the main producer of ATP

- In the Krebs cycle, NADH and H are produced from NADH.
- NADH then transfers the hydrogen atom to the respiratory chain (also called electron transport system) where electrons are transported in a series of oxidation-reduction steps to react, ultimately, with molecular oxygen.
- Cytochromes are electron transport intermediates containing haem of related prosthetic groups that undergo valency changes of iron atom. Haem is the same iron containing group that is oxygen carrying
- pigment in haemoglobin.
The path of electrons in the respiratory chain appears to be as follows:
- NADH is oxidized by coenzyme Q. This oxidation yields enough free energy to permit the synthesis of a molecule of ATP from ADP and
- inorganic phosphate.








- Coenzyme Q is in turn oxidized by cytochrome b which is then oxidized by cytochrome c. This step also yields enough energy to permit the synthesis of a molecule of ATP.
- Cytochrome c then reduces a complex of two enzymes called cytochrome 'a' and as (for convenience the complex is referred as cytochrome a).
- Cytochrome 'a' is oxidized by an atom of oxygen and the electrons arrive at the bottom end of the respiratory chain.
- Oxygen is the most electronegative substance and the final acceptor of the electrons.
- A molecule of water is produced. In addition, this final oxidation provides enough energy for the synthesis of a third molecule of ATP.

**FTB**

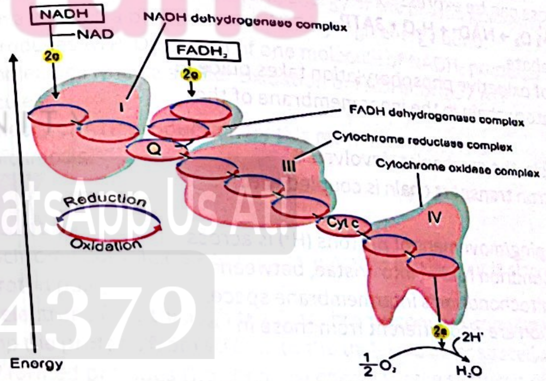
In this chain, the reduced **NADH** and **$FADH_2$** are oxidized and their electrons are passed along a series of oxidation reduction reaction to the final acceptor i.e., molecular oxygen.

**BTB**

- Whenever hydrogen is removed from a substrate there are seven intermediate hydrogen acceptors to catch the atom.
- They are NADH reductase complex (FMN and Fe-S), FADH reductase or co-enzyme Q or Ubiquinone (UQ) and four cytochromes that is **b, c, and a3.**
- Electrons are passed to ubiquinone; at this step an electron is split off the hydrogen atom.
- The proton becomes free, and electron is passed successively from coenzyme Q to cytochrome b, c, and a3.
- The energy is released at three steps, flavoprotein to ubiquinone, cyt. b to c, a to a3.

## COMPONENTS OF ELECTRON TRANSPORT CHAIN

- The components of electron transport chain include:
- NADH- dehydrogenase complex (I).
- FADH-dehydrogenase complex (II)
- Coenzyme Q
- Cytochrome reductase complex (III)
- Cytochrome-c
- Cytochrome oxidase complex (IV).




- NADH is oxidized when it reacts with NADH- dehydrogenase complex (1). Electrons now move to the co-enzyme Q.
- If $FADH_2$ is to be oxidized through ETC, it also hands over its electrons to coenzyme Q, via FADH dehydrogenase complex (II).
- The flowing electrons from coenzyme Q are now transferred to cytochrome reductase complex (III) which hands over its electron to cytochrome c.
- Like co-enzyme Q, cytochrome c is also mobile carrier of

**DO YOU KNOW?**

- In Krebs cycle the extracted electrons are temporarily housed within NADH and $FADH_2$ molecules.
- These enter in electron transport system where $H^+$ are removed, ATP and $H_2O$ are formed.

electrons. Cytochrome c delivers the electrons to cytochrome oxidase complex (IV).

- Finally, the electrons are transferred to oxygen. The oxygen is the ultimate acceptor of electrons. It becomes reactive.
- Each oxygen atom also picks up a pair of hydrogen ions from the aqueous solution forming water.
- Energy released during passage of electrons from one carrier to the next is used to pump protons ($H^+$) from the mitochondrial matrix to the inter membrane space.
- There are three such sites, corresponding to three enzymes present in the electron transport chain i.e.
- NADH-dehydrogenase complex (I)
- Cytochrome reductase complex (III)
- Cytochrome oxidase complex (IV).
- The electron transport chain makes no ATP directly.
- Its function is to ease the fall of electrons from food to oxygen releasing energy in manageable amounts.
- How does the mitochondrion couple this electron transport chain and energy to ATP synthesis? The answer is a mechanism called chemiosmosis.

**SCIENCE TIDBITS**

- Ubiquinone is not a protein, but a small molecule soluble in lipids and insoluble in water
- Cytochromes literally means cell colour. The reduced cytochromes are pink in colour.
- They are protein plus pigment molecules containing iron. They can gain or lose an electron. Normal rate of **heartbeat** in a

## OXIDATIVE PHOSPHORYLATION

- Synthesis of ATP in the presence of oxygen is called oxidative phosphorylation.
- Normally, oxidative phosphorylation is coupled with the respiratory chain.
- As already described ATP is formed in three steps of the respiratory chain.
- The equation for this process can be expressed as follows:

**$NADH + H^+ + 3ADP + 3P_i + \frac{1}{2}O_2 \rightarrow NAD^+ + H_2O + 3ATP$**

- Where Pi is inorganic phosphate.
- The molecular mechanism of oxidative phosphorylation takes place in conjunction with the respiratory chain in the inner membrane of the mitochondrion.
- Here also, as in photosynthesis, the mechanism involved is chemiosmosis by which electron transport chain is coupled with synthesis of ATP.
- In this case, however the pumping/movement of protons ($H^+$) is across the inner membrane of mitochondrion folded into cristae, between matrix of mitochondrion and mitochondrion's intermembrane space.
- The coupling factors in respiration are also different from those in photosynthesis.

| Enzyme | Inhibitor | Enzyme |
|---|---|---|
| Phosphofructokinase | High level of ATP | Phosphofructokinase |
| Pyruvate decarboxylase | High level of NADH | Pyruvate decarboxylase |

## CHEMIOSMOSIS

- In both cyclic and non-cyclic photophosphorylation, the mechanism for ATP synthesis is chemiosmosis, the process that uses membranes to couple redox reactions to ATP production.





- Electron transport chain pumps protons ($H^+$) across the membrane of thylakoids in case of photosynthesis into the thylakoids space.
- The energy used for this pumping comes from the electrons moving through the electron transport chain.
- This energy is transformed into potential energy stored in the form of $H^+$ gradient across the membrane.
- Next, the hydrogen ions move down their gradient through special complexes called ATP synthase which are built in the thylakoid membrane.
- During this diffusion of $H^+$ the energy of electrons is used to make ATP.

**FTB**

- Oxidative phosphorylation is the synthesis of ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH, $FADH_2$) produced in respiration.
- The enzyme required for this synthesis is called ATP synthetase.
- It is located in the inner mitochondrial membrane.
- It consists of two parts i.e., Fo and F1. Fo is embedded in the membrane and involves in the movement of protons from inter-membrane space to mitochondrial matrix.
- F1 or elementary particle is a head like part which is projected from the surface of membrane towards matrix.
- It catalyses ATP synthesis by the combination of ADP and Pi. ATP-synthetase becomes active in ATP formation only when a proton gradient having higher concentration of $H^+$ or protons on the Fo side as compared to F1, side is established.
- The flow of protons through the Fo channel induces F1 particles to function as ATP-synthetase i.e., the energy of the proton gradient is used in attaching a phosphate to ADP by high energy bond.
- This produces ATP. Oxidation of one molecule of $NADH_2$ produces 3 **ATP** molecules while a similar oxidation of $FADH_2$ forms 2 ATP molecules.
- The theory of ATP production by this mechanism is called chemiosmosis.

**FTB**

- Cytochrome complex is not only an electron carrier, but it also works as proton pump.
- The electrons flow through the Cytochrome complex stimulates it to pump the protons from stroma to the thylakoid inner space(lumen)
- ATP formed provides the chemical energy for the synthesis of sugar during dark reactions.

**NOTE**

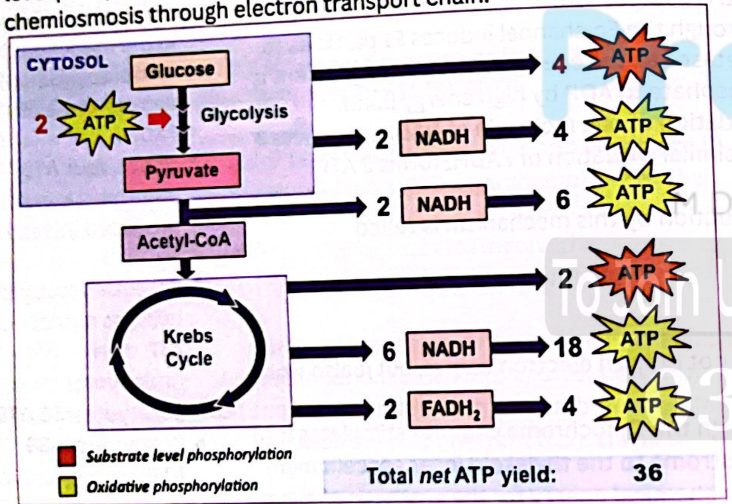
- The two molecules of the NADH of glycolysis are produced in cytoplasm.
- These cannot be taken up by mitochondria because the mitochondrial membrane is impermeable for NADH.
- Therefore, at the time of their uptake only the energized electrons of NADH are transferred inside the mitochondrion by a complex mechanism.
- These electrons are received by two molecules of FAD+ in the mitochondrial matrix to produce two molecule of $FADH_2$.
- Hence, four ATP molecules are produced instead of six.
- So, eukaryotes yield two less number of ATP than prokaryotes.
- Eukaryotes=**36 ATP**
- Prokaryotes =**38** ATP

## SUBSTRATE LEVEL PHOSPHORYLATION

- The prime objective of cellular respiration is to generate ATPs.
- There are two ways to do this during aerobic respiration: chemiosmosis and substrate level phosphorylation, the former we have already discussed.
- As far as substrate level phosphorylation is concerned, you are

already familiar that the addition of inorganic phosphate to any organic molecule is called phosphorylation.

- When phosphate is enzymatically transferred from an organic substrates molecule it is called substrate level phosphorylation.
- However, it accounts for only a small percentage of the ATP that a cell generates.
- It occurs at three occasions during aerobic respiration:
- In glycolysis, substrate level phosphorylation occurs, when 1,3-bisphosphoglycerate is converted into 3-phosphoglycerate **(7th reaction)** and when phosphoenol pyruvate is converted into pyruvate **(10th reaction)**. There are four ATPs produced by this mechanism during glycolysis but two of them are supposed to be consumed in preparatory phase so net product by substrate level phosphorylation is **2 ATP**.
- In Krebs cycle, substrate level phosphorylation occurs when succinyl CoA is converted into succinate. There are two molecules of ATP produced at this occasion.
- Since, ATP can be synthesized directly from the organic substrates of exergonic reactions (energy releasing reactions e.g., cellular respiration), therefore, it is said that substrate level phosphorylation couples the exergonic reactions with the synthesis of ATP.
- These ATP are then used to drive endergonic reactions (energy storing reaction e.g., protein synthesis).
- In this way, out of total **36 ATP** which are produced during aerobic respiration in most of human cells, **4 ATP** are the result of substrate level phosphorylation and remaining **32 ATP** are produced by chemiosmosis through electron transport chain.



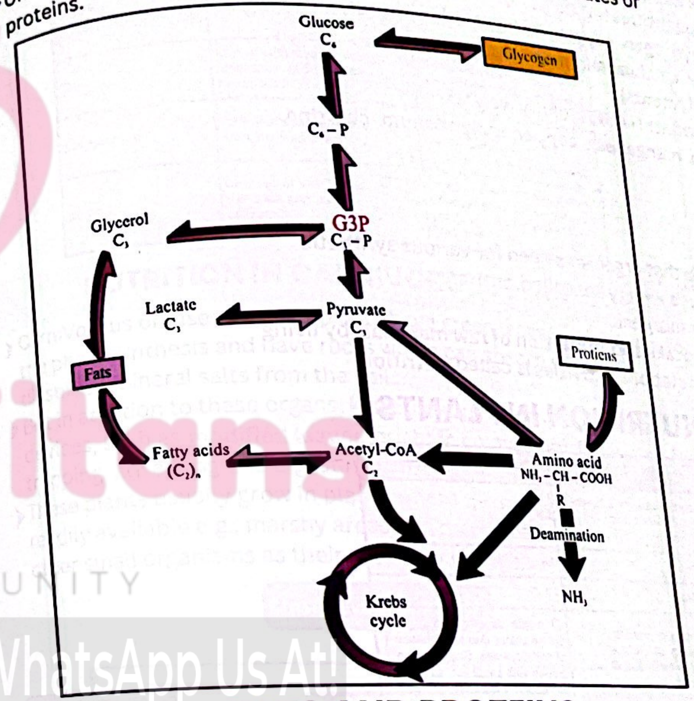

| Pathway | Co-enzyme Yield | Substance Level Phosphorylation | Oxidative Phosphorylation | Total ATP |
|---|---|---|---|---|
| Glycolysis | 2 NADH | 2 ATP | 2 NADH = 4 or 6 ATP* | 6 or 8 ATP* |
| Pyruvic Acid Oxidation | 2 NADH | - | 2 NADH = 6 ATP | 6 ATP |
| Kreb's Cycle | 6 NADH, 2 $FADH_2$ | 2 ATP | 6 NADH = 18 ATP, 2 $FADH_2$ = 4 ATP | 24 ATP |
| TOTAL | - | 4 ATP | 32 ATP | 36 or 38 ATP |



**NOTE** *Two ATPs can be used in the transport of two NADH molecules produced in glycolysis, from the cytosol to the mitochondria.*

## IMPORTANCE OF G3P (PGAL)

- Glyceraldehyde 3-phosphate (G3P) is an important intermediate of respiration and photosynthesis. In respiration.
- G3P appears during glycolysis pathway which leads to the formation of pyruvate.
- In the Calvin cycle of photosynthesis, G3P molecules are converted into glucose phosphate within the chloroplast.
- Phosphate is then converted to glucose, fructose, sucrose and starch.
- One gram fat provides **2.5 times** more energy than carbohydrates or proteins.




## FATS AND PROTEINS

- Cellular respiration of fats and proteins when a fat is used as an energy source, it breaks down to glycerol and three fatty acids.
- Glycerol l is converted to G3P, a metabolite in glycolysis.
- The fatty acids are converted to acetyl-CoA, which enters the Krebs cycle.
- An **18-carbon fatty acid** results in nine acetyl-CoA molecules.
- The hydrolysis of proteins results in amino acids whose R-group size determines whether the carbon chain is oxidized in glycolysis or the Krebs cycle. The carbon chain is produced in the liver when an amino acid undergoes deamination, i.e., the removal of the amino group.
- The amino group becomes ammonia ($-NH_2$), which enters the urea cycle and becomes part of urea.

CHAPTER 08

# NUTRITION

## Nutrition

- Nutrition is the process of uptake and utilization of raw materials by living organisms for various metabolic activities.
- Hydroponics is a method used to test whether an element is **essential** for plant growth. It involves growing plants in **aerated water** with added mineral salts.
- 16 essential elements have been identified for plant growth.
- Macronutrients (9 elements):
- Required in large quantities (>0.05% of dry weight).
- Includes carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium.
- Micronutrients (7 elements):
- Needed in trace amounts (<0.05% of dry weight).
- Includes iron, boron, manganese, copper, molybdenum, chlorine, and zinc.

**FTB**

- All those **raw materials** that organisms need for various synthetic activities and to produce **energy** are called **nutrients.**
- They may be organic or inorganic.
- All the process of the uptake and **utilization of raw materials** by living organisms for **various metabolic activities** is called **nutrition.**

## MINERAL NUTRITION IN PLANTS

| Macronutrients | Major Functions | Deficiency Symptoms |
|---|---|---|
| Carbon | Component of carbohydrates, lipids and nucleic acid molecules | Nil |
| Hydrogen | As above | Nil |
| Oxygen | As above | Nil |
| Nitrogen | Components of proteins, nucleic acids, chlorophyll, Coenzymes NAD, NADP, Cytochromes. | Chlorosis, development of purple colour due to formation of anthocyanins. Suppression growth with small leaves early defoliation. Flowering delayed. |
| Phosphorus | In nucleic acids, phospholipids, ATP | Stunted growth and premature left fall, development of anthocyanin pigment, brown necrotic areas appear on leaves, petioles and fruits. Restricted growth of root and shoot. Poor development of vascular tissue, delayed flowering. |
| Calcium | In cell wall, involved in membrane permeability, enzyme activator. | Meristematic regions badly effected. Chlorosis of margins of young leaves leading to necrosis. Flowering suppressed or premature fall of flowers. |
| Magnesium | In chlorophyll, enzyme activator in carbohydrate metabolism | Interveinal chlorosis. Formation of anthocyanin pigments. Necrosis in severe cases. |
| Sulphur | In certain amino acids and vitamins. | Stunted growth. Chlorosis first appearing in younger leaves. Formation of anthocyanin |





| | | |
|---|---|---|
| Potassium | Osmosis and ionic balance, opening and closing of stomata, enzyme activator. | Stunted growth. Mottled chlorosis, necrotic shriveling or leaves. Decrease in apical dominance. In cereals development of weak stem. |
| **Micronutrients** | **Major Functions** | **Deficiency Symptoms** |
| Chlorine | Ionic balance involved in photosynthesis. | Welting of leaf tips, following by chlorosis, bronzing and necrosis. |
| Iron | Part of enzymes involved in photosynthesis, respiration and nitrogen fixation. | Interveinal chlorosis. Localised or generalized chlorosis. |
| Manganese | Part of enzymes involved in respiration and nitrogen metabolism, required for photosynthesis. | Chlorotic and necrotic spots in the interveinal regions of leaf. Leaves become mottled. |
| Copper | Part of enzymes involved in photosynthesis. | Necrosis in the young leaves at the tip and along the margins. Exanthema in citrus tree and reclamation disease in cereals and legumes. |
| Zinc | Part of enzymes involved in respiration and nitrogen metabolism. | Decreased growth. Reduction in size of internodes. Mottled left condition. |
| Molybdenum | Part of enzymes involved in nitrogen metabolism | Mottling and necrosis in older leaves. Deficiency causes whiptail disease in cauliflower |
| Boron | Involved in membrane transport and calcium utilization | Death of stem and root apices. Leaves become thick, curled and brittle. Flower production greatly reduced. |

## NUTRITION IN CARNIVOROUS PLANTS

- CarniVorous or insectivorous plants have green leaves which serve for the photosynthesis and have roots which can absorb water and dissolved mineral salts from the soil.
- But in addition to these organs, insectivorous plants have special devices, such as **modified leaves,** bright in colours which are used for trapping, attracting and digesting insects and other small organisms.
- These plants usually grow in places where **nitrogenous salts** are not readily available e.g., marshy areas and therefore they use insects and other small organisms as their source of nitrogen.

Insectivorous Plants

Pitcher plant(saracenia pupurea)

Venus Flytrap(Dionaea muscipula)

Sundew(Drosera intermedia)

## NUTRITION IN INSECTIVOROUS PLANTS

- Some plants **supplement** their inorganic diet with **organic compounds by trapping and digesting insects** and small animals.
- These plants are **true autotrophs,** but their **growth becomes more rapid** when they capture prey
- **Nitrogenous compounds** obtained from animal bodies are beneficial for these plants.
- In some species, **trapped insects are decomposed by bacteria,** while in others, **enzymes secreted by the leaves** digest the prey.
- The plants **absorb the nitrogenous compounds** formed during

**KPK**

- Carnivorous plants may be sub divided into two **major groups;** those which have passive traps and those with **active traps.**
- For some of these traps the actual method of insect decomposition involves digestive enzymes produced by the plant and bacterial decay within the trap.
- A classic passive trap is the "pitfall trap" of pitcher plants including **Darlingtonia** and **Sarracenia** of the Sarraceniaceae, and **Nepenthes** of the Nepenthacea where an insect falls into a vase like a modified leaf.
- **Downward pointing** hairs on the slippery walls prevent the insect from crawling out, and the helpless victim ultimately drowns in a pool of digestive enzymes at the bottom.
- **Examples** of active traps are the **"flypaper"** or adhesive traps of sundews **(Drosera, Droseraceae)** and butterworts **(Pinguicula, Lentibulariaceae)**
- In both of these

digestion.

## PITCHER PLANT (SARRACENIA PUPUREA)

- Leaves are modified into a **sac-like pitcher**, partially filled with water.
- A **hood-like structure** at the leaf's end partly covers the open mouth of the pitcher.
- **Stiff hairs** inside the pitcher prevent trapped insects from escaping.
- **Bacteria or enzymes** break down the proteins of trapped insects, and the plant **absorbs the nutrients**.

## VENUS-FLY TRAP (DIONAEA MUSCIPULA)

- The **leaf is bilobed**, with a **midrib** in between.
- Each lobe has a row of **long stiff bristles** along its margins.
- When an insect touches the **sensitive hairs** on the leaf, the lobes **snap shut**, interlocking their bristles.
- Enzymes secreted from the glands on the leaf surface digest the trapped insect, and the plant **absorbs the nutrients**.

## SUNDEW (DROSERA INTERMEDIA)

- Leaves are modified with **numerous tentacle-like hairs**, each having a **gland at its tip**.
- **Odor from the plant** attracts insects, which become **entangled in the sticky tentacles.**
- **Enzymes digest the proteins** of the insects, and the plant **absorbs the nutrients.**

unrelated genera, the leaves are covered with sticky gland-tipped hairs (Drosera) or a sticky layer of mucilage (Pinguicula) which entangle the hopeless, struggling victim.

## DIGESTIVE SYSTEM OF MAN

Ingestion → Digestion → Absorption → Assimilation → Egestion

The **digestive system** consists of the **gastrointestinal tract (GIT)**, also called the **digestive tract** or **alimentary canal**, along with **accessory digestive organs** that aid in digestion

- **Viscera:** Refers to internal organs, including digestive organs like the **stomach and intestines**, but also non-digestive organs like the **spleen and lungs.**
- **Gut:** An anatomical term that typically refers to the **developing stomach and intestines**
- **Structure of the Digestive Tract**

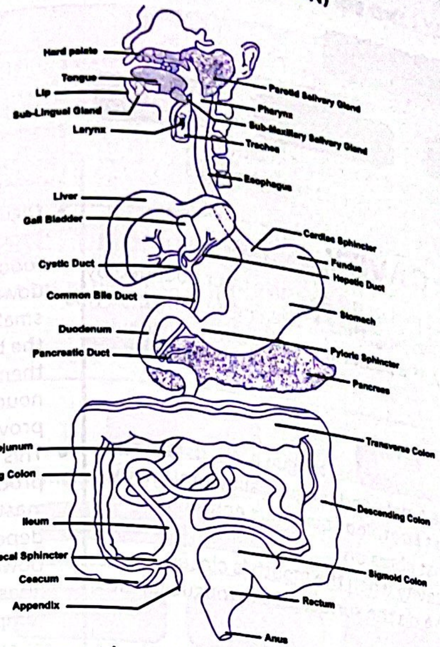
1. **Oral Cavity (Mouth)**
   - The **first section** of the digestive tract.
   - It opens **posteriorly into the pharynx**.
2. **Pharynx & Oesophagus**
   - The **pharynx** connects the **oral cavity** to the **oesophagus** (also spelled oesophagus in American English).
   - The **oesophagus** serves as a **passageway** to the **stomach.**
3. **Stomach**
   - Receives food from the **oesophagus.**
   - Opens **inferiorly into the small intestine.**
4. **Small Intestine**
   - The **first segment** is the **duodenum** (meaning: twelve fingers in length).

**BTB**

- The food is utilized at the cellular level, but most organic food except vitamins is present in large complex and non-diffusible, thus cannot be absorbed in the cell.
- Therefore, these large complex food particles must be broken down into simple and diffusible food, so that these molecules can easily pass through the wall of intestine into the blood then up to the cells.
- This is done through the process of digestion.








- The **middle segment** is the **jejunum** (meaning empty).
- The **final segment** is the **ileum** (meaning twisted).

5. **Large Intestine**
   - The **first segment** is the **cecum** (meaning: blind), which has the **vermiform appendix** (meaning: wormlike).
   - The **colon** is divided into **ascending, transverse, descending, and sigmoid** sections.
   - The **rectum** (meaning straight) connects to the **anal canal.**
6. Anus
   - The final termination of the digestive tract, where waste is expelled.

**FTB**

- The organs of GI tract include oral cavity, pharynx, oesophagus, stomach, small intestine and large intestine.
- The accessory organs include the teeth, tongue, salivary glands, liver, gallbladder and pancreas.
- The GI tract, which extends from the mouth to the anus, is a continuous tube.
- It is a locally differentiated structure. It is specialized at various points along its length with each region designed to carry out a different role in the overall process of digestion and absorption.
- GI is approximately 9m (30 ft) long.
- It traverses the thoracic cavity and enters the abdominal cavity at the level of diaphragm.

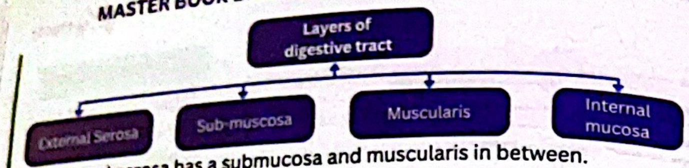
The digestive tube consists of four major layers, or tunics.

**SCIENCE TIDBITS**

- Inflammation of the parotid or parotis is called parotiditis or parotitis. The most common type of parotitis, caused by a viral infection, is mumps

**EXTRA INFORMATION**

- **Salivary amylase** digests starch.
- **Mucin** is a **proteoglycan** that gives a lubricating quality to the secretions of the salivary glands.
- Water moistens food and mucous membrane.
- Saliva also contains various **mineral salts** including chloride ions which speed up the activity of enzymes.
- Saliva **prevents bacterial infection** in the mouth as it contains lysozyme and immunoglobulin.
- Saliva has a **pH between 6.00 and 7.0**, a favourable for the digestive action of amylase.




- External serosa has a submucosa and muscularis in between.
- These four tunics (layers) are present in all areas of the digestive tract from the oesophagus to the anus.

## ORAL CAVITY

➤ The oral cavity, or mouth, is that part of the digestive tract bounded by the lips anteriorly, the fauces (meaning, throat, opening into the pharynx) posteriorly, the cheeks laterally, the palate superiorly and a muscular floor inferiorly.

**FTB**

- The mouth is surrounded by the lips, cheeks, tongue and a palate and includes a chamber between the palate and tongue called oral cavity.
- The oral cavity is lined with **moist stratified squamous epithelium**, which provides protection against abrasion.
- The tongue nearly fills the oral cavity when the mouth is closed.
- **Rough projections** called **papillae** on the surface of the tongue cause friction, which is useful in handling the food.
- These papillae also contain **taste buds**.
- The palate forms the **roof of the oral cavity**.
- It consists of a **hard anterior bony part the hard palate** and a **soft posterior non-bony part the soft palate.**
- Soft Palate consists of skeletal muscle and connective tissue.
- The **uvula** (meaning, a grape) is the projection from the posterior edge of the soft palate.
- The palate is important in the swallowing process, preventing food from passing into the nasal cavity.
- Palatine tonsils are located in the lateral wall of the fauces.
- There are **32 teeth** which are adapted to handle food in different ways.

| Name of Teeth | Shape of Teeth | Function |
|---|---|---|
| 1. Incisors (Front teeth) | Chisel-shaped with sharp edges | Used to bite off relatively large pieces of food |
| 2. Canines | Cone-shaped | Useful in grasping or tearing of food |
| 3. Pre-Molars and Molars | Flattened surfaces | Specialized for grinding of food particles |

## SALIVARY GLAND

➤ A considerable number of salivary glands are scattered throughout the oral cavity.
➤ There are **three pairs (6 in total)** of the large multicellular glands.
➤ As food moves through the digestive tract, secretions are added to liquefy and digest it and to provide lubrication.
➤ Each segment of the digestive tract is specialized to assist in moving its contents from the oral end to the anal end.

**KPK**

- Digestion is the process by which food is broken down into its smallest parts so the body can use them to build and nourish cells and to provide energy.
- This chewing process, known as **mastification**, is dependent upon powerful muscles **(masseter and temporalis)**, as well as smaller muscles that permit fine control; they move the mandible (lower jawbone) against the upper jaw and enable crushing of relatively hard food.
- Mastication causes exocrine glands under the tongue and in the back of the mouth to secrete a watery liquid called **saliva** which performs two essential functions.
- It **moistens and compacts the chewed food** so your tongue can roll it into a ball (bolus) and push it to the back of your mouth for swallowing and easy passage

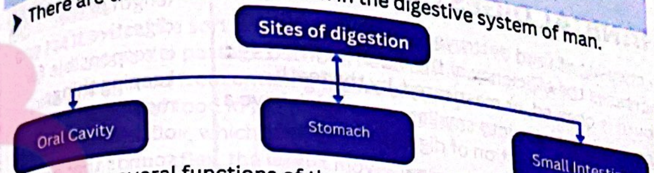




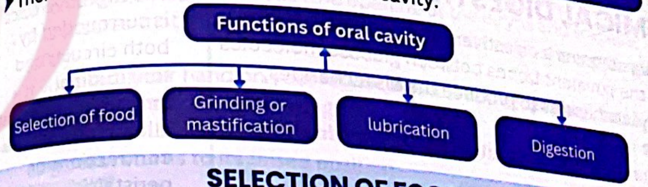
| Glands | Location | Secretions | Opening of Ducts |
|---|---|---|---|
| Parotid glands (Largest) | In front of ears | Saliva with amylase | Posterior part of oral cavity |
| Sub-mandibular/Sub-maxillary glands | Behind jaws | Saliva with amylase and mucus | Floor of oral cavity |
| Sublingual glands (Smallest) | Below tongue | Saliva with mucus only | Floor of oral cavity |

## FUNCTION OF THE ORAL CAVITY

➤ There are three sites of digestion in the digestive system of man.




➤ There are several functions of the oral cavity.




## SELECTION OF FOOD

➤ When food enters the oral cavity (the cavity bounded by palate, tongue, teeth and cheeks) it is tasted, smelled and felt. If the taste or smell is unpleasant or if hard objects like bone or dirt are present in the food, it is rejected.
➤ Oral cavity is aided in selection by the senses of smell, taste and sight.
➤ Tongue being **sensory and muscular organ** plays the most important role in selection of food through its taste buds.

## GRINDING OR MASTIFICATION

➤ After selection, the food is ground by means of molar teeth into smaller pieces. This is useful because: (a) the esophagus allows relatively small pieces to pass through and (b) small pieces have much more surface for the enzyme to attack.

## LUBRICATION AND DIGESTION

➤ These are the main functions of the oral cavity accomplished by saliva.
➤ Saliva produced by salivary glands contains three important ingredients

| Components | Role |
|---|---|
| Water and Mucus (Glycoprotein) | Form a slimy liquid that moistens and lubricates food for efficient chewing and smooth passage through the esophagus. |
| Sodium bicarbonate and other salts | Slightly antiseptic; primarily stabilize the pH of food. Fresh saliva starts with pH ~8 but drops to ~6 as $CO_2$ is lost. |

through the pharynx and esophagus.
- Almost no protein or fat digestion occurs in the mouth except the release of lingual lipase an enzyme secreted by **Ebner's glands** on the dorsal surface of the tongue

**BTB**

- Both jaws have **32 permanent teeth (20 milk teeth)**, as embedded in their sockers in the gums.
- Teeth are of four types, **Incisors 2/2, canine 1/1, Premolar 2/2** and **Molar 3/3.**
- Teeth help in grasping and grinding of food.
- The **brainstem** contains the reflex centres and cranial nerves responsible for controlling swallowing.

**KPK**

- The actions of the teeth and tongue prepare food for swallowing
- The swallowing procedure is **regulated by nerves in the medulla oblongata and pons.**
- **Choking** is a reflex action when food or liquid passes into the trachea, it

| | |
|---|---|
| Ptyalin (Salivary Amylase) | A carbohydrate-digesting enzyme that breaks down starch and glycogen into maltose. |

**FTB**

- In the oral cavity **mechanical and chemical digestion** takes place
- **Mechanical digestion** is the physical division of a mass of food into smaller masses.
- **Chemical digestion** is the chemical conversion of larger molecules into smaller molecules

## MECHANICAL DIGESTION

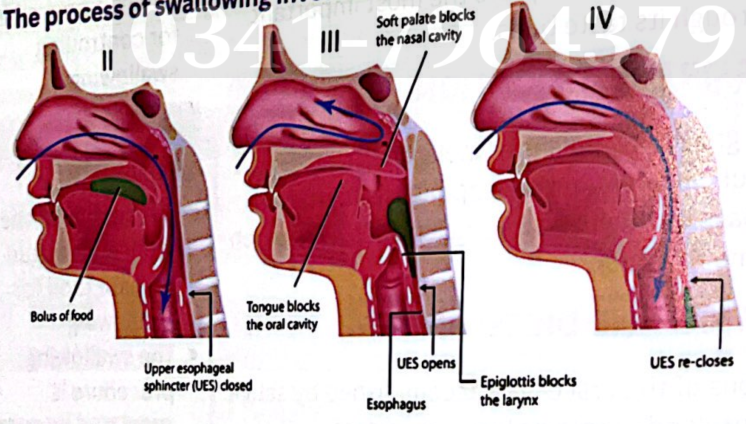
- Cooking and thorough chewing of food destroys the cellulose of starch covering and increases the efficiency of the digestive process.
- Food taken into the mouth is chewed, or masticated, by the teeth.
- Mastication breaks large food particles into smaller ones, which have a much larger total surface area for the action of digestive enzymes.

## CHEMICAL DIGESTION

- The watery part of saliva contains a digestive enzyme called salivary amylase, which breaks the covalent bonds between glucose molecules in starch and other polysaccharides to produce the disaccharides, maltose and isomaltose.
- Only about **3%-5% of the total carbohydrates are digested in the mouth.**

## SWALLOWING

- As a result of mastication, the softened, partially digested, and slimy food mass is rolled into a small oval lump called a bolus. The tongue and pharyngeal muscles push the bolus to the back of the mouth while preventing it from entering the windpipe.
- **The process of swallowing involves the following steps:**




- **Tongue Movement:** The tongue moves upward and backward against the roof of the mouth, forcing the bolus to the back of the oral cavity.
- **Soft Palate Action:** The tongue's backward movement pushes the soft palate upward, closing the nasal opening at the back.
- **Epiglottis Positioning:** The tongue forces the **epiglottis** (a flap of cartilage) into a horizontal position, covering the glottis (the windpipe opening).
- **Larynx Elevation:** The **larynx** (cartilage surrounding the windpipe)

it involves **forceful** ... **of air thro**... larynx to c... airway

- Food trave... the mouth ... stomach in... **to 8 secon**...
- Peristalsis ... throughout length of th... digestive tr... is responsib... keeping thi... moving and occasional s... sounds that
- The **digestiv**... is surrounde... both **circula**... **longitudinal smooth** mus... allows for **rh**... **contractions** peristalsis.
- Food enters t... stomach fron esophagus, th... the lower esophageal.

moves upward beneath the tongue.

- **Glottis Closure:** The glottis partially closes due to the contraction of a ring of muscles.
- **Food Passage:** The epiglottis directs the food mass to one side of the glottis, ensuring it safely enters the **esophagus** instead of the windpipe.
- Swallowing begins as a **voluntary** action, but once food reaches the back of the mouth, the process becomes **automatic** (involuntary).
- The bolus is then pushed down the esophagus by **peristalsis** (wave-like muscular contractions).

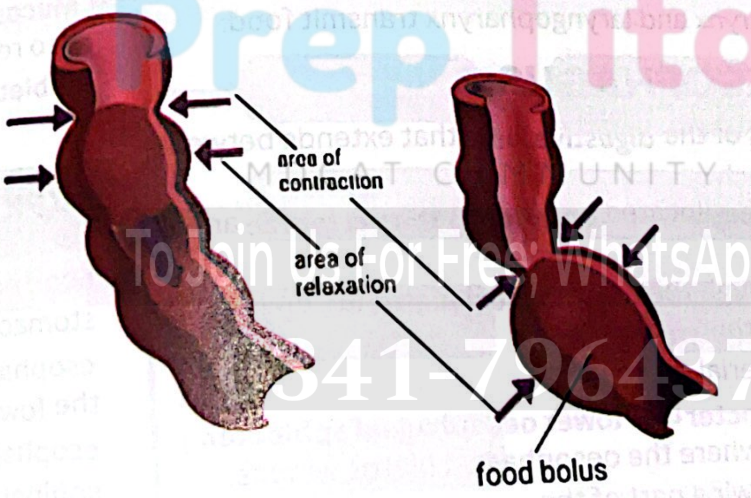
**FTB**

- Muscles raise the soft palate against the back wall of the pharynx, which closes the passage between nasal cavity and pharynx, preventing food from entering the nasal cavity.
- The pressure of food in the pharynx stimulates nerves, triggering the **swallowing reflex**, which is involuntary.
- As part of this reflex, the **larynx** moves up to meet the **epiglottis**, which then covers the glottis (the opening of the larynx and trachea).
- This ensures that food bypasses the trachea and enters the esophagus safely.
- If you place your hand on your **larynx (Adam's apple)**, you can feel it move upward during swallowing.

Once food enters the **esophagus**, the soft palate lowers, and the epiglottis returns to its raised position

**PTB**

## PERISTALSIS




- Peristalses are characteristic movements of the digestive tract by which **food is moved along the cavity of the canal.**
- It consists of the **wave of contraction of the circular and longitudinal muscles** preceded by the wave of relaxation thus squeezing the food down along the canal.
- Peristalsis starts just behind the mass of food from the buccal cavity along the oesophagus to the stomach and then along the whole

alimentary canal.

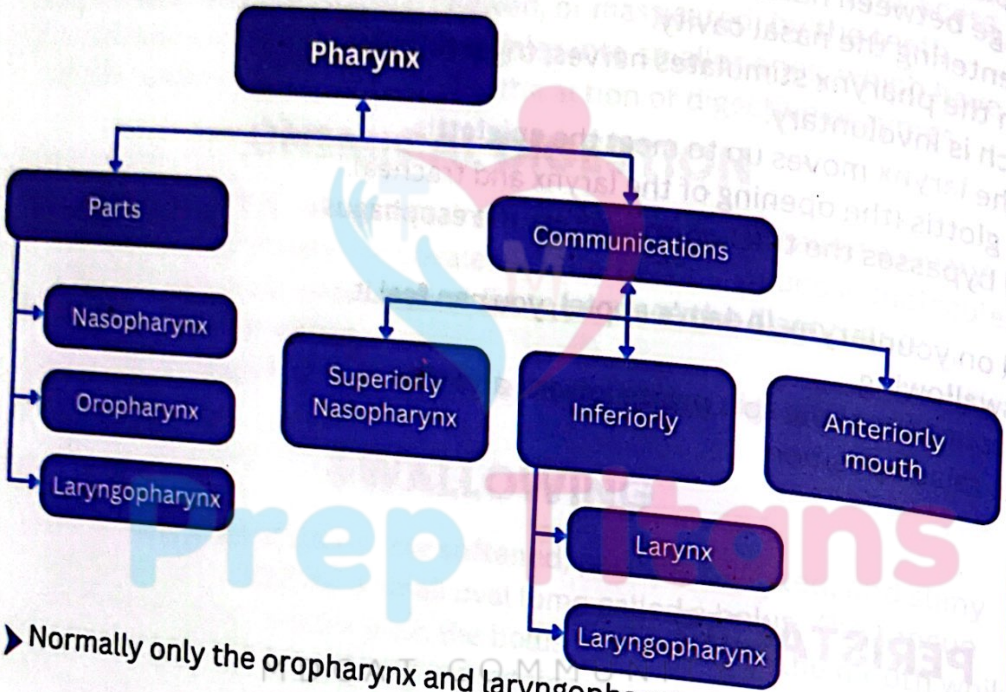
- Occasionally, the movements are reversed, with the result food may be passed from the intestine back into the stomach and even into the mouth.
- This movement is called **antiperistalsis**, leading to vomiting.

## HUNGER PANGS

- Hunger contractions are **peristaltic contractions** which are increased by **low blood glucose levels** and are sufficiently strong to create an uncomfortable sensation often called a "hunger pang"
- Hunger pangs usually begin **12 to 24 hours** after the previous meal or in less time for some people.

## PHARYNX

- It is a cavity behind the mouth.




- Normally only the oropharynx and laryngopharynx transmit food.

## OESOPHAGUS

- The **oesophagus** is the part of the **digestive tube** that extends between the **pharynx** and the **stomach**.
- It is approximately **25 cm long**, located **anterior to the vertebrae** and **posterior to the trachea**.
- The oesophagus passes through the **oesophageal hiatus** (an opening in the **diaphragm**) and ends at the **stomach**.
- Two sphincters regulate material movement:
- The **upper oesophageal sphincter** and **lower oesophageal sphincter**.
- A hiatal hernia is a condition where the oesophageal hiatus widens, commonly seen in adults, allowing part of the **stomach** to extend into the **thorax**.
- Parts of the **digestive system** are specialized to transport molecules from the **lumen** of the **digestive tract** into the **extracellular spaces**. The processes of **secretion**, **movement** and **absorption** are regulated by **nervous** and **hormonal mechanisms**.
- **Saliva** is secreted at a rate of about **1–1.5 litres per day**

**BTB**

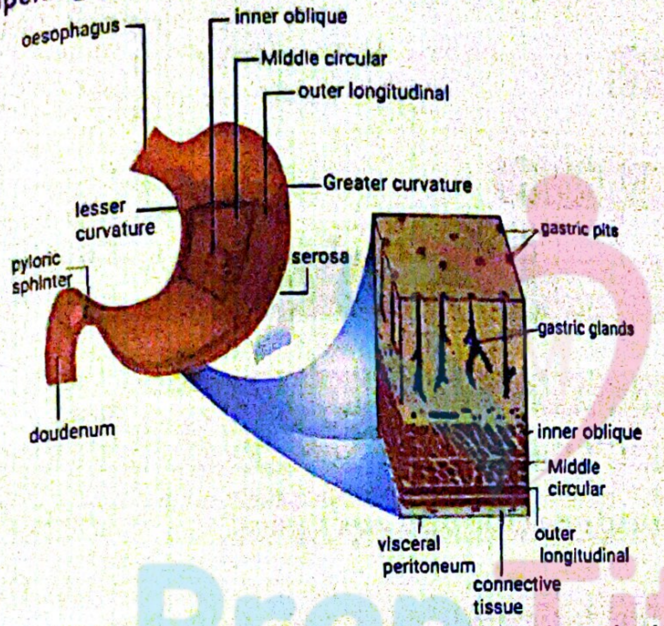
- The **stomach** is the widest part of the **digestive tract**.
- The innermost layer of the stomach is the **epithelium**, followed by the **mucosa**.
- The **serosa** is the thin outermost layer, connecting the stomach to the **abdominal wall**.
- The folds and wrinkles in the stomach wall are called **rugae**.
- **Zymogen cells** are also known as **principal cells**.
- **Mucous cells** are also referred to as **goblet cells**.

**KPK**

- Food enters the stomach from the **esophagus** through the lower **esophageal sphincter**.
- The stomach releases digestive hormones, enzymes, and **gastric juices** which help break down food molecules into the chyme into

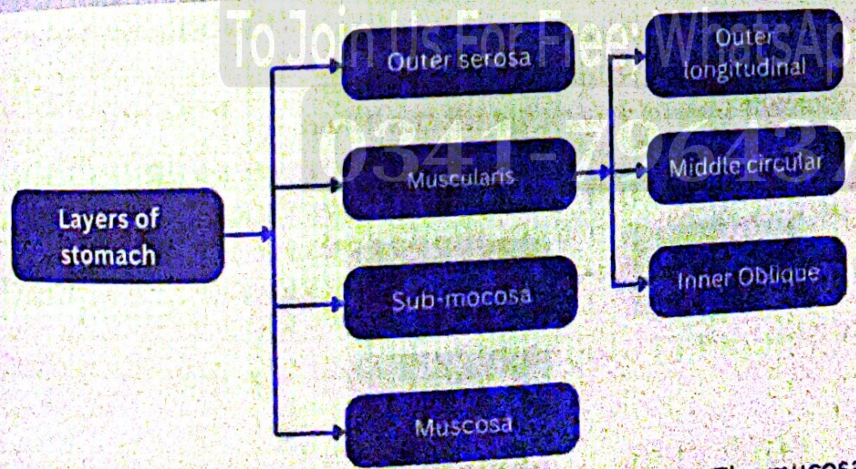
# STOMACH

- The stomach is an **enlarged segment** of the digestive tract, located in the **left superior part** of the **abdomen**, just below the **diaphragm**.
- When empty, it has a **J-shape**, and it connects to:
- The **oesophagus** (anteriorly).
- The **small intestine** (posteriorly).
- The **cardiac opening** connects the **oesophagus** to the **stomach**, surrounded by the **cardiac sphincter**.
- The **largest part** of the stomach is the **body**, which narrows to form the **pyloric opening**, guarded by the **pyloric sphincter**.




- A section of stomach wall that illustrates its histology, including several gastric pits and glands.

## LAYERS OF STOMACH






- The stomach is lined with **simple columnar epithelium**. The mucosal surface forms numerous tube-like gastric pits, which are the openings for the gastric glands.
- The **epithelial cells** of the stomach can be divided into four main
- types.
- The first type is surface mucous cells, which produce mucous, is on the surfaceS and lines the gastric pits.
- The remaining are in the gastric gland.

smaller particles for further digestion.
An empty stomach has a volume of approximately 50 ml. However, after a meal, it typically expands to about 1 liter and can stretch to hold as much as 4 liters of food.

**KPK**

**STRUCTURE OF STOMACH**

- The stomach is a muscular organ located on the left side of the upper abdomen.
- It is subdivided into **4 regions:**

**CARDIAC REGION**

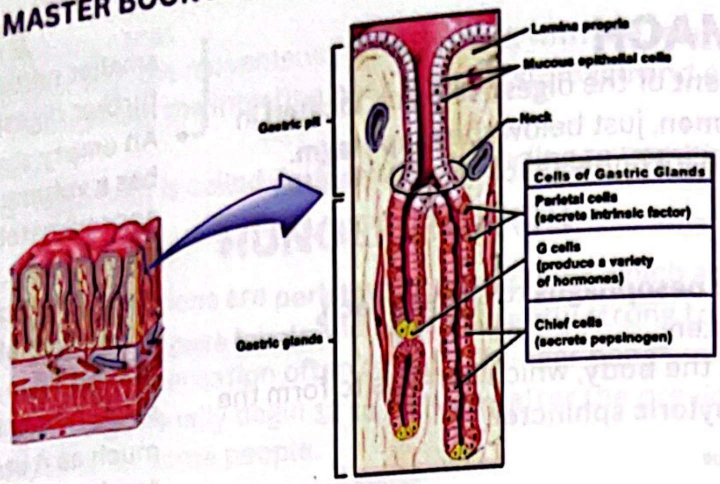
- Here the contents of the esophagus empty into the stomach through lower esophageal or cardiac sphincter.

**CARDIAC REGION**

- An expanded area curving up above the esophageal opening.

**CARDIAC REGION**

- Central and the largest region.




- Epithelial cells of stomach
  - Mucous
  - Cells of Gastric cells
    - Parietal / Oxyntic → Secrete HCL
    - Chief of zymogen → Pepsinogen
    - Endocrine cells → Gastrin

## FUNCTIONS OF STOMACH

- Digestion in the stomach can be divided into two types: mechanical digestion and chemical digestion.

### MECHANICAL DIGESTION

- The **mixing action** of the **stomach walls** facilitates **mechanical digestion.**
- The **smooth muscles** of the stomach produce **contractions** known as **mixing waves.**
- Unlike other parts of the **alimentary canal**, the **stomach** has **three layers** of **smooth muscle**, making the mixing action more efficient.
- The **churning action** of the stomach (mixing waves) blends the **bolus** with **gastric juice.**
- This **mixing** produces a **thick liquid** called **chyme.**

- Digestion in stomach
  - Mechanical Digestion → Churning
  - Chemical Digestion
    - Oxyntic cells
    - Zymogen cells
    - Mucus cells

### CHEMICAL DIGESTION

- Stomach secretions include mucus, hydrochloric acid, gastrin, intrinsic factor, and pepsinogen.

#### PYLORUS

- The narrow end of the stomach that joins the small intestine at the pyloric sphincter.
- Like the cardiac sphincter, the pyloric sphincter is a ring of muscle that stimulates the movement of food out of the stomach.
- The wall of the stomach is lined with millions of gastric glands, which together release 400-800 ml of gastric juice each meal.

#### EXTRA INFORMATION

##### HCL

- **Parietal cells** contain $H^+$ ions (protons).
- **Transmembrane proteins** in **parietal cells** secrete $H^+$ ions using **ATP energy.**
- The $H^+$ ion concentration in **gastric juice** can reach **0.15 M**, lowering the pH to **less than 1.**

##### MUCOUS SECRETING CELL

- Specialized mucous cells secrete a **protective mucus layer** on the **stomach walls**, preventing damage from **gastric acids.**
- Previously, **peptic ulcers** were thought

## MUCOUS CELLS

- The mucous cells secrete viscous and alkaline mucus.
- The thick layer of mucous lubricates and protects the epithelial cells of the stomach wall from the damaging effect of acidic chyme and pepsin.

## PARIETAL CELLS

- Parietal cells, found in the **gastric glands** of the **pyloric region,** secrete **intrinsic factor** and **hydrochloric acid (HCl).**
- **Intrinsic factor,** a **glycoprotein,** binds with **vitamin B12,** aiding its **absorption** in the **ileum.**
- **Hydrochloric acid (HCl)** maintains a **low stomach pH** (typically between **1 and 3,** but usually around 2).
- While **HCl** has a **minor digestive role,** its primary function is to **kill bacteria** ingested with food.
- The **low pH:**
- Stops carbohydrate digestion by inactivating salivary amylase.
- Denatures proteins, allowing proteolytic enzymes (pepsin) to access internal peptide bonds.
- Creates an optimal acidic environment for pepsin activity.

## CHIEF CELLS

- Chief cells in the **gastric glands** secrete **inactive pepsinogen.**
- **Pepsinogen** is stored in **zymogen granules** and released by **exocytosis** upon stimulation.
- Once in the **stomach lumen, pepsinogen** is converted to **pepsin** by:
- Hydrochloric acid (HCl).
- Previously formed pepsin molecules (autocatalysis).
- Pepsin functions optimally at **pH 3** or lower.
- It catalyses the **cleavage of peptide bonds,** breaking **proteins into smaller peptide chains.**

**PTB**

- At the junction between oesophagus and the stomach there is a special ring of muscles called **cardiac sphincter.**
- When the sphincter muscles contract, the entrance to the stomach closes and thus prevents the contents of the stomach from moving back into the oesophagus.
- It opens when a wave of peristalsis coming down the oesophagus reaches it.
- It is an elastic muscular bag that stores food from meals for some time, making discontinuous feeding possible.
- It also partly digests the food.
- These muscular layers help in churning and mixing the food with the stomach walls.
- The mucosa of the stomach possesses numerous tubular gastric glands, which are composed of **three kinds of cell:**
- Mucous cells, parietal or oxyntic cells, zymogen cells.
- The secretion of all these cells is collectively called **gastric juice.**
- The secretion of the gastric juice is regulated by smell, sight and

to result from **mucus erosion due to stomach acids.**

- **Recent research reveals that Helicobacter pylori (H. pylori) bacteria are the primary cause of gastric ulcers, as they invade the stomach lining.**

### HORMONE SECRETING CELL

- **Gastric gland secretion is** stimulated by the **hormone gastrin.**
- **Endocrine cells in the stomach release gastrin in response to food arrival.**
- **Gastrin promotes acid secretion and enhances gastric motility.**

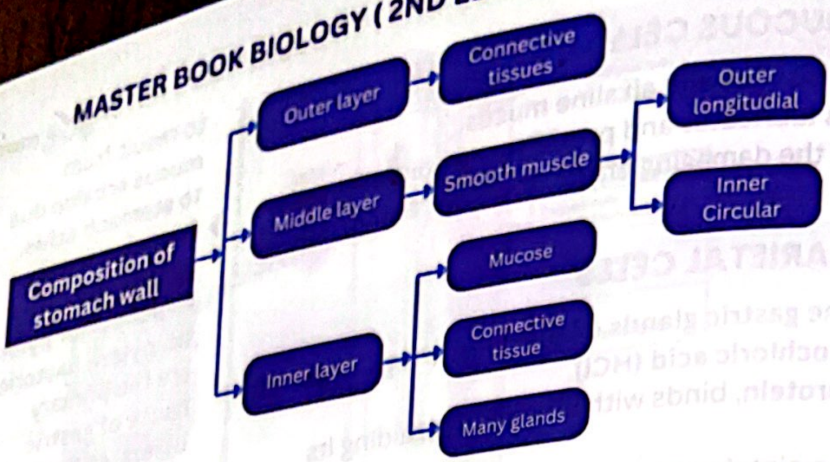
**KPK**

### ABSORPTION IN THE STOMACH

- Very little absorption occurs in the stomach.
- However, some water, certain ions, and drugs like aspirin and ethanol are absorbed from the stomach into the blood (accounting for the quick relief of a headache after swallowing aspirin

### FUNCTIONS OF THE STOMACH

- The stomach has three main functions.




quality of food.

- **Mucus** is a thick secretion that covers the inside of the stomach. It prevents the underlying walls from being digested.
- The **HCl** (secreted in concentrated form) adjusts the stomach content ranging from **2-3 pH** for pepsin to act on proteins.
- It also softens the food and kills many microorganisms taken in along with the food.
- Pepsinogen is the precursor to proteolytic enzyme pepsin.
- Pepsin hydrolyses protein to yield peptones and polypeptides.
- **Chyme** is a **semi-solid mass**. After the formation of chyme, it gradually empties into duodenum (the first segment of the small intestine where digestion occurs) through the relaxed pyloric sphincter.

## HEARTBURN OR PYROSIS

- Heartburn, or Pyrosis, is a painful burning sensation in the chest usually associated with the back flush of acidic chyme into the esophagus.
- This is due to overeating, eating fatty food, lying down immediately after a meal, consuming too much alcohol, caffeine or smoking.

## SIDE BOX

- If more protein is present in the food, it stimulates the production of gastrin hormone from the gastric endocrine lining, which is carried by blood to the gastric glands and stimulates them to produce more gastric juice.
- Thus, more proteins more gastrin and more gastric juice for digestion.

FTB

## ROLE OF NS& GASTRIN HORMONE ON THE SECRETION OF GASTRIC JUICE

- Approximately **2–3 liters** of gastric juice are produced daily, regulated by both nervous and hormonal secretions.
- Hormones that regulate stomach secretions include **gastrin**, secretin, gastric inhibitory polypeptide, and cholecystokinin.
- The taste, smell, and even pleasant thoughts of food stimulate tactile receptors and medullary centres that influence gastric secretion.
- Neuronal stimulation of the stomach mucosa releases **acetylcholine**, which activates parietal and chief cells and triggers gastrin secretion

### STORES THE FOOD

- It stores food, allowing us to consume large meals quickly and digest them gradually.
- Without the stomach's storage capacity, we would need to eat small amounts continuously, as the small intestine digests food very slowly.

### BREAKS DOWN FAT AND PROTEIN MOLECULES IN THE FOOD

- The stomach breaks down large fat and protein molecules so they can be absorbed in the small intestine.
- It releases powerful gastric juices containing hydrochloric acid and digestive enzymes.
- These acidic juices **(pH 1–3)** not only break down food but also kill bacteria.
- Strong muscular contractions churn the food into a paste called chyme, ensuring thorough mixing with the acids and enzymes.

### EMPTIES THE PARTIALLY DIGESTED CHYME

- It empties the partially digested chyme into the

from endocrine cells.

- Gastrin is released into circulation and travels to parietal cells, further stimulating gastric juice secretion.
- The presence of food (via stomach distention and amino acids/peptides) is the primary stimulus for maximal gastric secretion.
- Peristaltic waves occur less frequently, are significantly more powerful than mixing waves, and force the chyme near the periphery of the stomach toward the pyloric sphincter.
- The pyloric sphincter usually remains partially closed because of mild tonic contraction.
- Each peristaltic contraction is sufficiently strong to force a small amount of chyme through the pyloric opening and into the duodenum through the pyloric sphincter at a manageable pace.
- While the intestine digests food, the stomach continues to act as a storage area.
- Although absorption in the stomach is minimal, substances like iron and highly fat-soluble compounds (e.g., alcohol) are absorbed directly.

KPK

## WHAT CAUSES THE GASTRIC JUICE TO BE SECRETED?

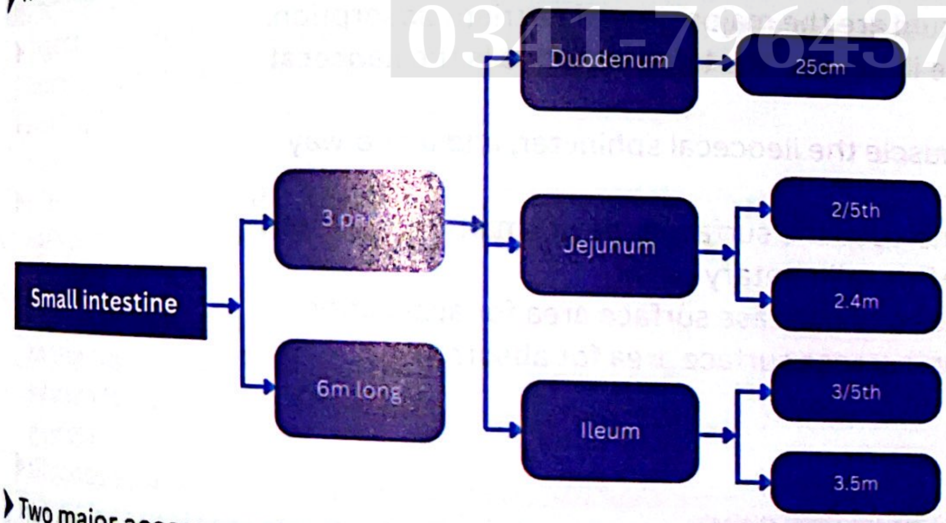
- Gastric juice secretion is controlled by chemical and nervous mechanisms.
- Even the sight, smell, taste, or sound of food can stimulate the nervous system to initiate a small secretion (e.g., mouthwatering).
- Pavlov's experiment demonstrated this reflex control: when a dog's esophagus was cut so food never reached the stomach, about one-fourth of normal gastric secretion still occurred, proving that gastric secretion is under reflex (nervous) control.
- Foods rich in protein send signals to the brain, which orders the gastric glands to secrete more juice.
- Protein molecules stimulate the endocrine cells of the stomach to release **gastrin**, which is absorbed into the blood and carried to the gastric glands, amplifying gastric juice secretion.
- Direct contact of food with the stomach lining also triggers gastrin release, further stimulating gastric secretion.

KPK

- The **duodenum**, the first segment of the small intestine, is about **10 inches long** (its name "duodenum digitorum" means twelve inches) and is roughly horseshoe shaped.
- Food takes **4–5 hours** to pass from the stomach into the duodenum.
- The **small intestine** is the longest part of the digestive tract at approximately **17 feet**, yet it is called "small" due to its narrow diameter (**3–4 cm**), about three times narrower than the large intestine.
- The **jejunum** is roughly **4–7 feet** long; its name comes from the Latin "jejunus," meaning empty.

## SMALL INTESTINE

- The small intestine consists of three parts.




- Two major accessory glands, the liver and the pancreas, are associated with the duodenum.
- When chyme passes from stomach into duodenum, its acidity stimulates the release of secretions from pancreas, liver and duodenal cells.

- Here most of the chemical digestion takes place

## DUODENUM

- The duodenum begins with a short superior part, which is where it exits the pylorus of the stomach ends in a sharp bend, which is where it joins the jejunum.
- Tiny finger-like projections of the mucosa form numerous villi (meaning. shaggy hair, which are **0.5-1.5 mm** in length.
- Each villus is covered by simple columnar epithelium and contains a blood capillary network, and a lymph capillary called a lacteal

**Anatomically segments of duodenum**

- Superior
- Descending
- Horizontal
- Ascending

## JEJUNUM & ILEUM

- The food, which escapes undigested from the duodenum, is completely digested in the jejunum and ileum by a group of enzymes contained in the intestinal juice.
- The overall picture of enzymes in the human digestive system, their substrates and final products is as follows.

| Enzymes | Substrates | Products |
|---|---|---|
| Amino peptidase | polypeptides | dipeptides |
| Erypsin | dipeptides | amino acids |
| Lipase | fats | fatty acids and glycerol |
| Maltase | maltose | glucose |
| Lactase | lactose | glucose and galactose |

- The jejunum and ileum are similar in structure to the duodenum, except that there is a gradual decrease in the diameter of the small intestine, the thickness of the intestinal wall, the number of circular folds and the number of villi as one progresses through the small intestine.
- The duodenum and jejunum are the major sites of nutrient absorption.
- The junction between the ileum and the large intestine is the **ileocecal junction**.
- It has a ring of smooth muscle the ileocecal sphincter, and a one-way ileocecal valve.
- The structural features increase the surface area of small intestine and make it the largest part of the alimentary canal.
- The internal walls are folded to increase surface area for absorption.
- Villi and microvilli further increase surface area for absorption

**FTB**

The Ileum is 5-? feet long and primarily functions to absorb nutrie...

**BTB**

- Duodenum is "C" shaped, about 20 to **30 cm in length.**
- It receives two alkaline fluids from liver and pancreas by a main duct called the hepatopancreatic ampulla.
- Burner's gland is found in ileum which produces intestinal juice (alkaline)

## FUNCTIONS

- The small intestine is the primary site for digestion and absorption.
- Gastric regulation begins when acidic stomach contents enter the duodenum, triggering the release of secretin, which in turn inhibits gastric secretion by acting on parietal and chief cells.

- Fatty acids and lipids in the duodenum and proximal jejunum stimulate the release of gastric inhibitory peptide and cholecystokinin.
- Intestinal secretions both lubricate and protect the intestinal wall from acidic chyme and digestive enzymes while keeping chyme in a liquid state.
- Most digestive enzymes in the small intestine come from the pancreas, although the intestinal mucosa also produces enzymes on its surface. That remain associated with the intestinal epithelial surface.
- Mucus is secreted in large amount by duodenal glands, intestinal glands, and goblet cells. The mucus provides the wall of intestine with protection against the irritating effects of acidic chyme and against the digestive enzymes that enter the duodenum from the pancreas.
- Secretin and cholecystokinin are released from the intestinal mucosa and stimulate hepatic and pancreatic secretions.
- Secretion by duodenal glands is stimulated by the vagus nerve, secretion, and chemical or tactile irritation of the duodenal mucosa.

## MOVEMENT IN SMALL INTESTINE

- The primary mechanical events in the small intestine are the mixing and propulsion of chyme.
- Segmental contractions mix the contents, while peristaltic contractions propel them along the digestive tract.
- The ileocecal sphincter remains mildly contracted but relaxes under peristaltic waves to allow chyme to pass into the cecum.

## ABSORPTION AND TRANSPORT

- Although some molecules can be absorbed throughout the digestive tract (e.g., via the oral mucosa), most absorption occurs in the duodenum and jejunum, with some in the ileum.
- Small molecules like alcohol and aspirin can pass through the stomach epithelium into the circulation.

### CARBOHYDRATES

- Ingested carbohydrates consist primarily of polysaccharides and monosaccharides such as glucose and fructose.
- During digestion, polysaccharides are broken down into monosaccharides.
- Digestion begins in the oral cavity with partial starch digestion by salivary amylase and is completed in the intestine by pancreatic amylase.
- The resulting monosaccharides are transferred by facilitated diffusion to the capillaries of the intestinal villi and carried by the hepatic portal system to the liver, where non-glucose sugars are converted to glucose.
- Glucose enters cells through facilitated diffusion.

### LIPIDS

- Lipid digestion begins with emulsification, accomplished by bile salts secreted by the liver.
- Pancreatic lipase then digests lipids into free fatty acids and glycerol,

**KPK**

**ABSORPTION OF NUTRIENTS**

- Most nutrient absorption occurs in the **small intestine.**
- Although its diameter is small, the intestinal walls are covered in **rugae** (wrinkles) lined with millions of **villi**, which are further studded with **microvilli**. This complex structure provides a surface area roughly the size of a tennis court.
- **Lacteal lymph vessels** absorb digested fat into the lymphatic system (which drains into the bloodstream), while blood vessels take up other nutrients and transport them via the **hepatic portal vein** to the liver.
- In the liver, blood is filtered, toxins are removed, and nutrients are processed.
- The liver regulates blood glucose levels: excess glucose is converted to **glycogen** (in response to insulin) and stored, while falling glucose levels trigger the conversion of

with cholesterol and phospholipids also produced.
- Once digested, bile salts form micelles (a small morsel) around lipid droplets.
- When a micelle contacts an intestinal epithelial cell, its contents diffuse through the lipid cell membrane.

## LIPID TRANSPORT

- In intestinal epithelial cells, triacylglycerol is reformed.
- Proteins combine with triacylglycerol to form chylomicrons, which exit the cell and enter the lacteals in the villi.
- Chylomicrons are carried via the lymphatic system to the bloodstream.
- Before entering adipose cells, triacylglycerol is broken down into fatty acids and glycerol, which are then reassembled and stored.
- In the liver, chylomicron lipids are stored, converted, or used for energy.
- Because lipids are insoluble or only slightly soluble in water, they are transported in the blood bound to proteins as lipoproteins which are water-soluble.
- Chylomicrons are one type of lipoproteins.

## PROTEIN

- Pepsin, secreted by the stomach, cleaves proteins into smaller polypeptide chains.
- After the stomach, pancreatic proteolytic enzymes further digest proteins into small peptide chains.
- These peptides are broken down into dipeptides, tripeptides, and amino acids by peptidases on the microvilli of the small intestine.
- Dipeptides and tripeptides enter intestinal epithelial cells, where dipeptidase and tripeptidase split them into individual amino acids.
- The amino acids then enter the hepatic portal system and are transported to the liver, where they may be modified or released into the bloodstream.
- Most amino acids are used to form new proteins, while some are used for energy.

## WATER

- About **9 litres** of water enters the digestive tract each day, of which about **92%** is absorbed in the small intestine, and another **6%-7%** is absorbed in the large intestine.
- Water can move in either direction across the wall of the small intestine by osmosis

## IONS

- Sodium, potassium, calcium, magnesium, and phosphate ions are also actively transported

## EXTRA POINTS

- Gastric inhibitory peptide strongly inhibits gastric secretion, and cholecystokinin inhibits gastric secretions to a lesser degree.
- Hypertonic solutions in the duodenum and jejunum also inhibit

glycogen back to glucose (via glucagon).

**SCIENCE TIDBITS**

- Certain drugs, which are lipid-soluble and can diffuse through the cell membranes of the oral cavity, can be quickly absorbed into the circulation.
- An example is nitroglycerine, which is a vasodilator used to treat cases of angina pectoris.
- The drug is placed under the tongue, where, in less than a **minute**, it dissolves and passes through the very thin oral mucosa into the lingual vein.

**SCIENCE TIDBITS**

- Lipoproteins are referred to as high or low-density lipoproteins.
- A lipoprotein with high lipid content has a very low density (LDL), whereas a lipoprotein with high protein content has a relatively high density (HDL).
- Chylomicrons, which are made up of **99% lipid** and only **1% protein**, have an extremely very low density.

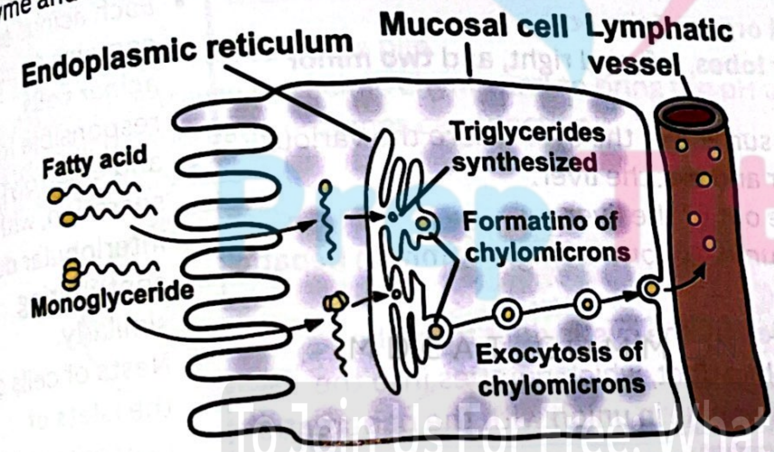
gastric secretions.

- The mucosa of the intestine produces secretions that primarily contain mucus, electrolytes, and water.

PTB

## ABSORPTION OF FOOD

- Nearly all absorption of the products of digestion takes place in the ileum.
- Electron microscope reveals that these cells have countless, closely packed cylindrical processes, microvilli (brush borders)
- Simple sugars and amino acids are absorbed by diffusion or active transport into the blood capillaries through the microvilli.
- Some of the fatty acids and glycerol are also absorbed into blood stream.
- However, a large proportion of fatty acids and glycerol enter the epithelial cells of villi, where they recombine into fats.
- These fats then enter the lacteals.
- Proteins present in lymph vessels combine with fat molecules to form lipoprotein droplets.
- These pass into blood stream via thoracic lymphatic duct.
- The lipoproteins are subsequently hydrolysed by blood plasma enzyme and enter body cells, where they may be used.

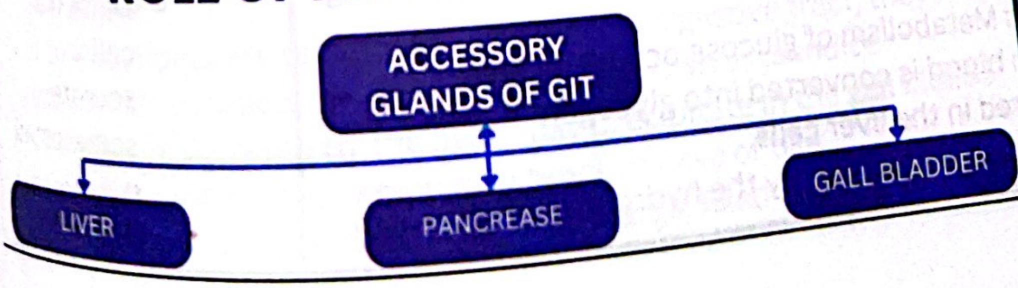





### SIDE BOX

- Many humans develop intestinal gas and diarrhoea from consuming milk product, because they lack the enzymes for digesting lactose in milk.
- The epithelial cells of villi are constantly shed into intestine. These cells are replaced by the new cells moving up due to in respiration or stored as fat in the liver, muscle of rapid cell division in crypts under the skin.

## ROLE OF ACCESSORY GLANDS




BTB

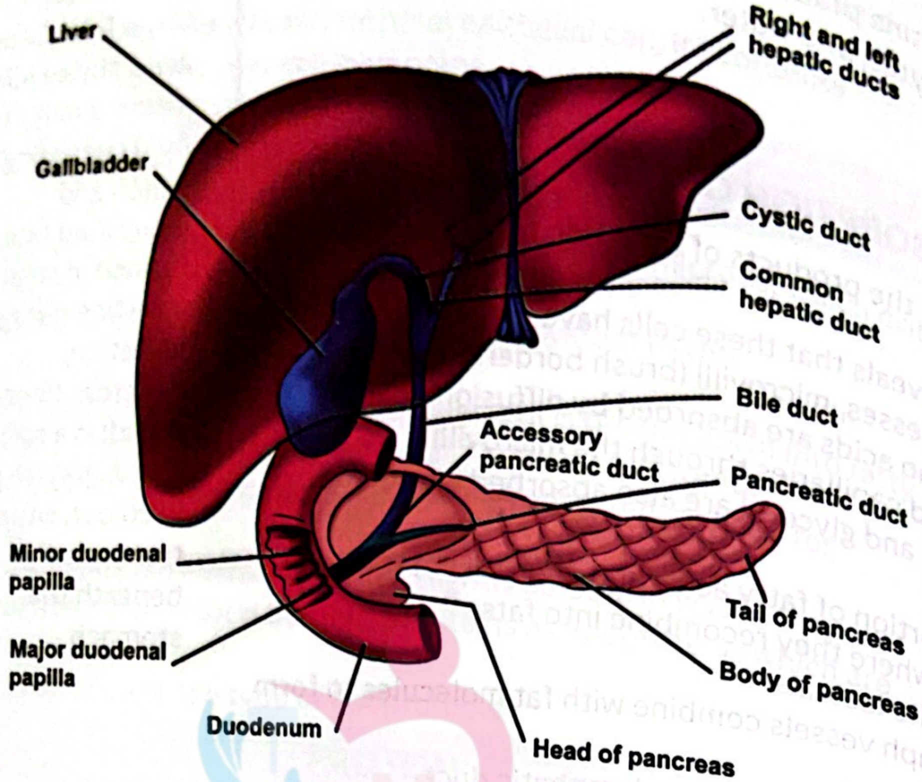
- Chyle from Greek word chylos juice, means a milky body fluid consisting of lymph and emulsified fats, formed in small intestine during digestion.
- Pancreas (Sweet bread) is a soft gland, greyish pink in colour, situated transversely beneath the stomach.

KPK

- Bile is typically **yellowish-green colour.**
- **Liver is centre of heat production.** (i.e., geyser of body).
- **Synthesis of vitamin A** from carotenoid and **synthesis of albumin** from amino acids takes place in liver.
- Denaturation of fatty acids and phosphorylation of fats takes place in liver cells

### PANCREASE REGION

- The **head** is an expanded portion lying in the C-shaped region of the duodenum, intimately attached




## LIVER

- The liver is the **largest internal organ** of the body.
- The liver consists of **two major lobes**, left and right, and **two minor lobes**.
- A **porta (gate)** is on the inferior surface of the liver where the various vessels, ducts, and nerves enter and exit the liver.
- The **hepatic ducts** transport bile out of the liver.
- The right and left hepatic ducts unite to form a single **common hepatic duct**.
- The **common hepatic duct** is **joined by** the **cystic duct** from the gallbladder to form the common bile duct, which empties into the duodenum at the **major duodenal papilla** in union with the pancreatic duct.



### FUNCTIONS OF LIVER

- The liver performs **important digestive** and **excretory functions**, stores and processes nutrients, synthesizes new molecules and detoxifies harmful chemicals.
- **Liver hepatocytes** can **remove sugar from the blood** and store it in the form of glycogen.
- They can also **store fat, vitamins (A, B, D, E, and K), copper** and **iron**.
- This storage function is usually short-term and the amount of stored material in the hepatocytes varies, thus the cell size fluctuates during a given day.
- **Metabolic role of liver:** Metabolism of glucose occurs in liver.
- Excess of glucose from blood is converted into glycogen **(glycogenesis)** and stored in the liver cells.
- Whenever needed, glucose is obtained by the hydrolysis of glycogen

by connective tissue and ... common blood supply.
The **body** and ... extend across midline toward hilum of the ...

**KPK**

- The pancreas comprises two components— **acinar cells** and **ducts**—which constitute 80... of its mass.
- Twenty to forty acinar cells form unit called an acinus, in which **acinar cells** se... digestive enzy...
- Each acinus also contains **Centr... acinar cells**, responsible for ... and electrolyte secretion, with interlobular du... contributing similarly.
- Nests of cells c... the **islets of Langerhans** (ab... **2%** of the mass) consist of:
  - Alpha (α) cells: secrete glucagon.
  - Beta (β) cells: secrete insulin.
  - Delta (Δ) cells: secrete somatost...n.
  - F cells:

glycogenolysis)

- Glucose is also synthesized from amino acids or fatty acids and glycerol (**gluconeogenesis**).
- **Excess of amino acids** undergo **deamination** producing pyruvic acid and ammonia.
- Ammonia produced by deamination of amino acids in hepatic cells is converted to urea **(ornithine-arginine cycle)**.
- Formation of **blood proteins** (like prothrombin, fibrinogen) are synthesized in liver cells.
- These are necessary for blood clotting.
- **Phagocytosis** also occurs in liver i.e. **Kupffer cells** destroy dead RBCs.
- **The bile pigments** bilirubin and biliverdin are formed from the breakdown of haemoglobin.
- Liver produces **heparin**, an enzyme that prevents clotting of blood inside the blood vessels.
- It breaks RBCs after completion of **120 days** life span.
- Red blood cells are formed during foetal life.
- **Detoxification** occurs in liver.
- Liver cells detoxify or inactive the toxic substances like cresol, carbolic acid, etc. (produce by intestinal bacteria) or convert them to non-toxic substances.
- Similarly prussic acid produced during metabolism is converted into non-toxic substance.

## BILE PRODUCTION

- The liver produces and secretes bile.
- Bile helps to neutralize the acidic chyme and to bring the pH up to a level at which pancreatic enzymes can function.
- Bile salts **emulsify fats**

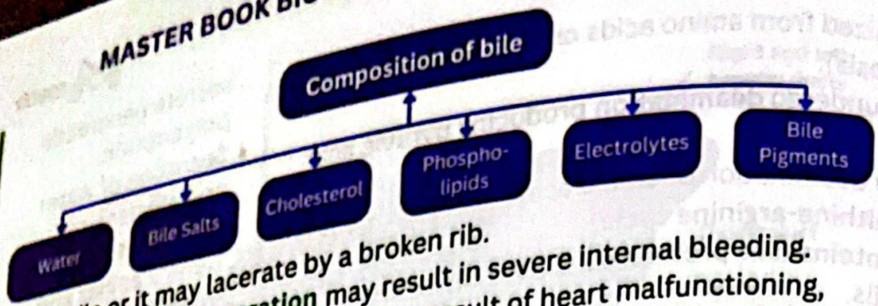

- Bile also contains excretory products such as bile pigments.
- **Bilirubin** is a bile pigment that results from the **breakdown of haemoglobin**.
- Most bile salts are reabsorbed in the ileum and carried in the blood back to the liver, where they stimulate further bile secretion.

**PTB**

- Bile contains **no digestive enzymes**, but its green colour is due to the bile pigments, which are formed from the breakdown of haemoglobin in the liver.
- If bile pigments are prevented from leaving digestive tract, they may accumulate in blood, causing a condition known as jaundice
- Cholesterol, secreted by the liver, may precipitate in the gall bladder to produce **gall stones**, which may block release of bile.
- The liver is easily ruptured because it is large, fixed in position, and

secrete pancreatic polypeptide.

- Secretion of water and electrolytes originates from Centro acinar and intercalated duct cells, while digestive enzymes are produced by acinar cells.
- The final product is a colourless, odorless, alkaline fluid containing enzymes (amylase, lipase, trypsinogen); **500–800 ml** is secreted daily.
- The alkaline pH results from secreted bicarbonate, which neutralizes gastric acid and regulates intestinal pH, aiding in the digestion of carbohydrates, proteins, and fats.
- Acinar cells synthesize isozymes (amylases, lipases, proteases) in the endoplasmic reticulum and package them in zymogen granules; these are released into the acinar lumen and transported into the duodenum, where they are activated.
- **Amylase** is secrete in an active form and functions optimally at **pH 7**, hydrolysing starc and glycogen




fragile or it may lacerate by a broken rib.

- Liver rupture or laceration may result in severe internal bleeding.
- The liver may become enlarged as a result of heart malfunctioning, hepatic cancer or may be damaged due to hepatitis or being alcoholic

## GALL BLADDER

- The gallbladder is a saclike structure on the inferior surface of the liver that is about **8 cm** long and **4 cm** wide.
- The gallbladder is connected to the common bile duct by the cystic duct.

## FUNCTIONS OF GALL BLADDER

- Bile is continually secreted by the liver and stored in the gallbladder.
- While the bile is in the gallbladder, water and electrolytes are absorbed, and bile salts and pigments become as much as **5 to 10 times** more concentrated than they were when secreted by the liver.

## PANCREASE

- The pancreas is a complex organ composed of both endocrine and exocrine tissues (hetero gland) that perform several functions.
- The pancreas consists of a **head**, located within the curvature of the duodenum, **a body and a tail**, which extends to the spleen.
- The endocrine part of the pancreas consists of pancreatic islets (islets of Langerhans).

## FUNCTIONS OF PANCREASE

- The exocrine secretion of the pancreas is called **pancreatic juice** and has **two major components:** an **aqueous component** and an **enzymatic component**.

### AQUEOUS COMPONENT

- The aqueous component is **produced** principally **by columnar epithelial cells** that line the smaller ducts of the pancreas.
- It contains **sodium** and **potassium ions** in about the same concentration found in extracellular fluid.
- Bicarbonate neutralizes the acidic chyme that enters the small intestine from the stomach.

### ENZYMATIC COMPONENT

- The enzymatic component of the pancreatic juice is produced by the acini cells of the pancreas and is important for the digestion of all major classes of food.
- Without the enzymes produced by the pancreas, lipids, proteins, and carbohydrates are not adequately digested.
- The proteolytic pancreatic enzymes, which digest proteins, are

into glucose, maltose, maltotriose, and dextrins. Lipase functions best at pH 7–9.

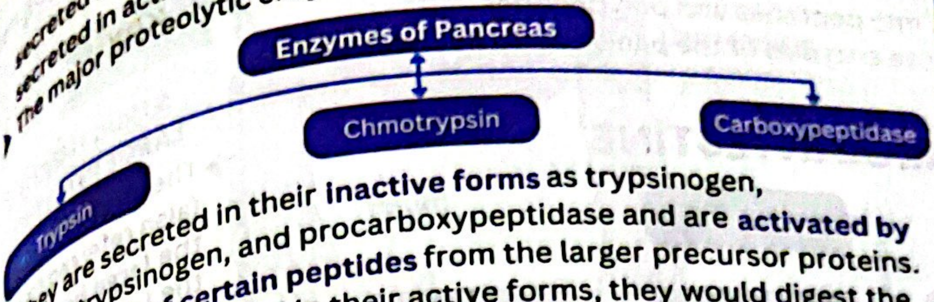
- The duodenal enzyme **enterokinase** converts trypsinogen into trypsin, which in turn activates chymotrypsin, elastase, carboxypeptidase, and phospholipase.
- **Secretin**—the first hormone discovered and acting like a "fireman"—is secreted in response to duodenal acidification from liquefied ingesta; its principal target is the pancreas, which responds by secreting a bicarbonate-rich fluid through the pancreatic duct.

**KPK**

- Large intestine is the final section of the gastrointestinal tract, and its main function is to remove water (plus any remaining minerals) from the food waste and compress it into a form for easy expulsion from the body.
- As the chyme

secreted in inactive forms, whereas many of the other enzymes are secreted in active form.

- The major proteolytic enzymes are:




- They are secreted in their **inactive forms** as trypsinogen, chymotrypsinogen, and procarboxypeptidase and are **activated by the removal of certain peptides** from the larger precursor proteins.
- If these were produced in their active forms, they would digest the tissues producing them.
- **Trypsinogen is activated by** the proteolytic enzyme **enterokinase** (meaning, intestinal enzyme), which is an enzyme attached to the brush border (microvilli) of the small intestine,
- Trypsin then activates more trypsinogen, as well as chymotrypsinogen and procarboxypeptidase
- Pancreatic juice also contains **pancreatic amylase,** which continues the polysaccharide digestion that was initiated in the oral cavity.
- In addition, **pancreatic juice** contains a group of lipids digesting enzymes called **pancreatic lipases,** which break down lipids into free fatty acids, glycerides, cholesterol, and other components.
- Enzymes that reduce DNA and ribonucleic acid to their component nucleotides, **deoxyribonucleases** and **ribonucleases,** respectively are also present in pancreatic juice.

## CONTROL OF PANCREATIC SECRETION

- The exocrine secretions of the pancreas are controlled by both hormonal and neural mechanisms.
- Secretin stimulates the secretion of a watery solution that contains a large number of bicarbonates ions from the pancreas.
- The primary stimulus for secretin release is the presence of acidic chyme in duodenum.


passes through the large intestine, the water is removed, and the chyme is combined with mucus and bacteria (gut flora) and is converted into feces.

- As in the esophagus and small intestine, undigested food is propelled through the large intestine by waves of muscular contraction and expansion, called peristalsis.
- However, unlike in the small intestine where these waves occur at irregular interval peristalsis in the large intestine is continuous.
- In addition, **2-3 times a day,** a vigorous type of movement **(gastrocolic reflex)** occurs which propels material towards the rectum and anus.
- As waste matter is pushed into the rectum, it trots a desire to defecate.

**FTB**

- Secretin stimulates the pancreas to release a watery secretion, rich in bicarbonate ions.
- Cholecystokinin causes the pancreas to release secretion rich in digestive enzymes.
- Parasympathetic stimulation from the vagus nerve causes the pancreas to release a secretion rich in digestive enzymes.

**BTB**

- The large intesti[ne] is a wide tube w[hich] begins with the ileum of small intestine and e[nds] to anus.

It is about **2 m**

**PTB**

- Carbohydrat... pancreatic amylase also called

## ABSORPTION OF WATER AND SALTS

- The material that passes from the small intestine to the large intestine contains a large amount of water, dissolved salts and undigested material.
- Water and salts are absorbed into blood, while undigested material is rejected as faces.

## ROLE OF USEFUL BACTERIA

- Large intestine also harbours a large population of **useful bacteria** that synthesize some vitamins especially **vitamin K**, which are absorbed in blood.

## FAECAL MATTER

- The faecal matter contains a large number of bacteria, plant fibres, sloughed of mucosal cells, mucus, cholesterol, bile pigments and water

**FTB**

- The large intestine performs several important functions.

### ABSORBING WATER AND ELECTROLYTES

- Further digestion or breaking down of nutrients does not take place in the large intestine.
- Proximal half of the large intestine functions to reabsorb some of the water and electrolytes making the stools solid.
- The substances that remain in the tube become feces, which are stored for a time in the distal portion of the large intestine.

### ABSORBING WATER AND ELECTROLYTES

- The large intestine also helps in absorption of vitamins made by bacteria that normally live in the large intestine.
- The most important of these is Vitamin K and Biotin (a B vitamin).

### ABSORPTION OF VITAMINS

- The large intestine also helps in absorption of vitamins made by bacteria that normally live in the large intestine.
- The most important of these is Vitamin K and Biotin (a B vitamin).

### REDUCING ACIDITY

- Secretes bicarbonates neutralize the increased acidity resulting from the formation of these fatty acids and other digestive components at earlier parts of the intestines

### PROTECTING FROM INFECTIONS

- Acts as a mucosal barrier and protects from microbial infections and invasions

## PROBLEMS OF LARGE INTESTINE

### DIARRHOEA

### COLON

- The colon is the ... part of large intestine, about ... to 1.8 meter long and consists of ... parts.
- The ascending colon runs upwards and then runs to ... left transversely ... called transverse colon, which goes down wards on left side of the abdomen known as descending colon.
- It forms "S" shaped curve called as sigmoid colon and join the last part of the large intestine known as rectum.

### RECTUM

- (L. rectus, straight) about **6 inch (15cm)** long tube, runs straight downwards join the anal canals **(4cm long)** and open to the external skin by a round opening call anus.

### FUNCTION OF LARGE INTESTINE

- Absorption of water and salts from the chyme takes place in the large intestine.
- The remaining chyme which is feces is yellowish or brownish in color due to the presence of bile pigments.
- It consists of cellulosebacteria, mucin, water and

- If the absorption of water and salts does not take place due to infection, drug action or emotional disturbance, a condition known as diarrhoea occurs.
- If this condition is unchecked, **dehydration** develops that may prove to be fatal.

## CONSTIPATION

- The other extreme condition is constipation, which is caused by the **excessive absorption of water.**
- It results in very slow less frequent bowel movement and is hard for movement of feces.
- In extreme conditions it leads to bleeding.

undigested substances.

- The odor of the feces comes from the bacterial decomposition of nitrogenous compounds

### MOVEMENT IN THE LARGE INTESTINE TAKES PLACE

- The peristaltic waves push the chyme into the ascending colon.
- Dissension of the rectal wall due to deposition of feces acts as a stimulus that initiates the defecation reflex.
- The external anal sphincter (composed of striated muscles) is consciously controlled, prevents the movement of feces out of the rectum and through the anal opening. If this sphincter is relaxed voluntarily, feces expelled.

## FUNCTIONS OF DIGESTIVE ORGANS

| Organ | Function | Secretion |
|---|---|---|
| Oral Cavity<br>Teeth | Mastication (cutting and grinding of food); communication. | None |
| Lips and Cheeks | Manipulation of food; holds food in position between the teeth; communication. | Saliva from buccal glands (mucous only). |
| Tongue | Manipulation of food; holds food in position between teeth; cleansing teeth and taste | Some mucous; small amount of serous fluid. |
| Salivary glands<br>Parotid gland | Secretion of saliva through ducts to posterior portions of oral cavity. | Saliva with amylase. |
| Submandibular glands | Secretion of saliva in floor of oral cavity. | Saliva with amylase and mucous. |
| Sublingual gland | Secretion of saliva in floor of oral cavity. | Saliva with mucous only. |
| Pharynx | Swallowing | Some mucous |
| Esophagus | Movement of food by peristalsis from pharynx to stomach. | Mucous |
| Stomach | Mechanical mixing of food; enzymatic digestion; storage; absorption. | |
| Mucous cells | Protection of stomach wall by mucous production. | Mucous |
| Parietal cells | Decrease in stomach pH. | HCl |
| Zymogen cells | Protein digestion. | Pepsinogen |
| Endocrine cells | Regulation of secretion and motility. | Gastrin |
| Accessory glands<br>Liver | Secretion of bile into duodenum. | Bile |
| Gall bladder | Bile storage; absorbs water and electrolytes to concentrate bile. | No secretions of its own, stores and concentrates bile. |
| Pancreas | Secretion of several digestive enzymes and bicarbonate ions into duodenum | Trypsin, chymotrypsin, pancreatic amylase, pancreatic lipase, bicarbonate ions. |

| | | |
|---|---|---|
| Small intestine<br>Duodenal glands<br>Goblet cells<br>Absorptive cells<br>Endocrine cells | Protection<br>Protection<br>Secretion of digestive enzymes and absorption of digested materials<br>Regulation of secretion and motility. | Mucous<br>Mucous<br>Enterokinase, amylase, peptidases, sucrase, maltase, lactase, lipase.<br>Gastrin, secretin. |
| Large intestine<br>Goblet cells | Absorption, storage and food<br>Movement.<br>Protection | Mucous |

## COMMON DISORDERS RELATED TO HUMAN DIGESTIVE SYSTEM

| Disorder | Description | Cause/s | Symptoms and Complications | Treatment |
|---|---|---|---|---|
| Dyspepsia | Incomplete or imperfect digestion | Acidity in stomach, faulty function of stomach, insufficient quantity and quality of bile | Abdominal discomfort, flatulence, heartburn, nausea, vomiting | Antibiotics, Cimetidine |
| Food Poisoning / Botulism | Illness from indigestion of food contaminated with toxins; severe form of food poisoning | Clostridium botulinum, Salmonella spp., Complyobacter spp. Entering through unpasteurized milk or improperly cooked meat | Abdominal pain, nausea, vomiting, diarrhea, fatigue, dizziness, double vision, headache | Maintain good hygienic conditions, use ORS, Loperamide, antibiotics prescribed |
| Obesity | Accumulation of abnormal fats in the body | Over-eating, eating too much fatty food, hormonal | May cause hypertension, cardiac diseases, diabetes mellitus, stomach disorders | Reducing fatty food, regular exercise, balanced diet, hormonal therapy |
| Anorexia Nervosa | Loss of appetite due to fear of becoming obese | Psychological with the onset of puberty and sexuality | Weight loss, metabolic disturbance | Psychiatric therapy, feeding through some alternative route |
| Bulimia Nervosa | Characterized by the bouts of overeating fattening foods. | - | Self-induced vomiting, fasting, purging, serum electrolyte imbalance, recurring infections. | Overcome effects of weight loss and malnutrition. |
| Piles | Masses of dilated tortuous veins in anorectal mucosa | Unhygienic conditions | Bleeding, constipation, depressed urge to defecation, distention of rectum | Improve hygiene, increase roughage in food, use of laxatives, avoid sitting on hard surfaces, surgical removal |



| | | | | |
|---|---|---|---|---|
| Ulcer | Sore produced by the eating away of stomach or duodenum walls by digestive enzymes | Excess gastric HCl secretion | Development of hole, spilling of contents into the abdominal cavity | Antacids, Pills |
| Pyrosis | Painful burning sensation in the chest associated with the backflow of acidic chyme into the esophagus | Over-eating, eating fatty food, lying down immediately after meals, alcohol and caffeine consumption, smoking | Pain in the chest region | Decrease in acidity, avoid eating spicy food |

CHAPTER 09

# GASEOUS EXCHANGE

## RESPIRATION

"Respiration is one of the most important metabolic activities of all organisms, occur at two levels i.e. organismic & cellular level".

RESPIRATION
- Cellular level
  - Internal Respiration
  - Catabolic Process
  - Directly involved in producing of energy
  - Breakdown of complex molecules into simpler one`s by utilizing oxygen ,produce CO2 extracts & conserves energy from food into biologicaly useful form, i.e ATP
- Organismic level
  - External Respiration
  - Also called breathing or ventillation
  - Involves inhalling of o2 and exhalling of co2 between body fluid & environment
  - Gaseous exchange carried out only by diffusion

## RESPIRATORY SURFACE

The area where the gaseous exchange with the environment takes place is called **respiratory surface**. The following are the few important properties of respiratory surface.

Properties of respiratory surface
- Large surface
- Moisture
- Ventilation
- Capillary Network
- Thin epithilium

### LARGE SURFACE AND MOISTURE:

- The surface area should be extremely large and kept moist as it is seen in the lungs in the land vertebrates and in the gills in the case of fishes.

### THIN EPITHELIUM:

- The distance across which diffusion has to take place should be little.
- In most animals the epithelium which separates air and blood is only one cell thick.
- As a result, the distance for diffusion is very short.

### VENTILATION:

- Ventilation maintains a steep diffusion gradient.
- There is a big difference in the concentration of the gases at two points which brings about diff...

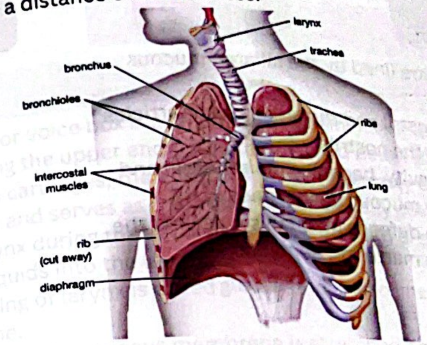


### CAPILLARY NETWORK:

- The respiratory site should possess extensive network of capillaries through which blood should low all the time at an adequate speed.
- In this way steep diffusion gradient is maintained which helps in rapid diffusion of oxygen.

**FTB**

The respiratory surface should be thin because diffusion is only efficient over a distance of **1mm** or less.




**PTB**

In man respiratory system includes lungs and air passages which are responsible for carrying fresh air to the respiratory sites.

Respiratory Tract
- Air Passage ways
  - Air tract
- Respiratory organ
  - Lungs

**FTB**

The human respiratory system can be divided into two regions, upper respiratory tract and lower respiratory tract.

Respiratory tract
- Upper Respiratory tract
  - Nasal Cavity
  - Pharynx
  - Larynx
- Lower Respiratory tract
  - Trachea
  - Bronchi
  - Lungs

## AIR PASSAGEWAY

- Air passageway consists of:
  - Nostrils • Nasal cavities • Pharynx • Larynx • Trachea • Bronchi
  - Bronchioles • Alveolar ducts • Alveolar sac

**FTB**

- **Upper respiratory tract** includes nasal cavity(nose) and pharynx.
- **Lower respiratory tract** includes larynx, trachea, bronchi, and lungs.

## NOSE

- Both the nostrils and nasal cavities are lined by the ciliated mucous membrane.
- Air enters the nasal cavity through nostril and the larger dust particles are trapped by the hair and mucus in the nostrils.
- Air, while passing through the nasal cavity, becomes moist, warm and filtered of smaller foreign particles by mucous membranes.
- Nose hair, mucous, and cilia serve as a defense mechanism against the harmful pathogens and the particulate matter present in air.

**PTB**

- Each nasal cavity is divided into **3 passageways** by the projection of nose from the walls of the internal nose.
- The nasal cavity leads into the throat or pharynx by two internal openings (internal nares).

**FTB**

- Nose is the only externally visible part of the respiratory system.

**Composition of nose**

- Bones
- Cartilage
- Fatty tissue

- External opening is called nostrils and the inner hollow spaces are called nasal cavities.
- Two nasal cavities are partitioned by means of nasal septum (the part of nasal bone).
- The anterior part of nostrils near the nostrils are called as vestibules which contain hair.
- Cilia move the trapped substances to pharynx for their removal.
- Underneath the mucous membrane there are blood capillaries that help to warm the air to about **30°C** depending on the external temperature.

## PHARYNX

- The pharynx is a muscular passage lined with mucous membrane.
- The air is channelized from the pharynx into the larynx.





**FTB**

- Pharynx is cone-shaped passageway leading from the oral and nasal cavities to the esophagus and larynx.
- The pharynx is part of the digestive system and also the respiratory system.

**Parts of Pharynx**

- Nasopharynx
- Oropharynx
- Laryngo-pharynx

## LARYNX

- The larynx or voice box is a complex cartilaginous structure surrounding the upper end of the trachea and below pharynx.
- One of the cartilages, the epiglottis has a muscularly controlled, hinge-like action and serves as a lid which automatically covers the opening of the larynx during the act of swallowing so as to prevent the entry of food or liquids into the larynx.
- The opening of larynx is called **glottis** and is also lined with mucous membrane.
- In the glottis the mucous membrane is stretched across into **two thin edged fibrous bands** called **vocal cords**, which help in voice production, when vibrated by air.

**FTB**

- Larynx is made of cartilage and muscles.
- Epiglottis (flap of elastic cartilage) usually stands upright and allows air to enter the larynx.
- During swallowing larynx is raised and epiglottis is pressed downward.

## TRACHEA

- The trachea is a membranous tubular structure lying ventral to the oesophagus and extends to the chest cavity or thorax where it is divided into right and left bronchi.
- It is also called **windpipe**.

**PTB**

- In the wall of trachea there are a series of C shaped cartilage rings which prevent the trachea from collapsing and keep the passage of air open.
- Trachea consists of dense regular tissues and smooth muscles reinforced with **15-20 C shaped** pieces of cartilage.

## BRONCHI AND BRONCHIOLES

- The trachea divides into right and left bronchi.
- Each bronchus on entering the lung divides and subdivides progress

progressively into smaller and smaller bronchi.

- When the smaller bronchi attain a diameter of one mm or less, then they are called **bronchioles**.
- Bronchi have the same cartilage rings as the trachea, but the rings are progressively replaced by irregularly distributed cartilage plates in secondary bronchi.
- The bronchioles and terminal bronchioles totally lack cartilage.

**Composition of Bronchioles**
- Ciliated cuboidel Epithilium
- Layers of circular smooth muscles

**PTB**

- Bronchioles are made up of mainly circular smooth muscles.

**FTB**

- The trachea divides to form to smaller tubes called the primary bronchi.
- The primary bronchi divide into secondary bronchi into each lung.
- There are two secondary bronchi in the left lung and there are three secondary bronchi in the right lung.
- Bronchi in turn gives rise to the tertiary bronchi.
- Bronchioles also sometimes divide further to form the terminal bronchioles.

**BTB**

- Bronchioles are made of ciliated cuboidal epithelium and a layer of circular smooth muscles.

## AIR SAC

- The bronchioles continue to divide and subdivide deep into the lungs and finally open into a large number of air-sacs.
- Air-sac is the **functional unit** of the lungs.

## ALVEOLI AND ALVEOLAR DUCT

- Each air-sac consists of several microscopic single layered structures called alveoli.
- The terminal bronchioles divide to form the alveolar duct. These alveolar ducts end at tiny air-filled chambers called alveoli.
- Overlying the alveoli there is a rich network of blood capillaries to produce an excellent site for the exchange of gases between air and blood.

**FTB**

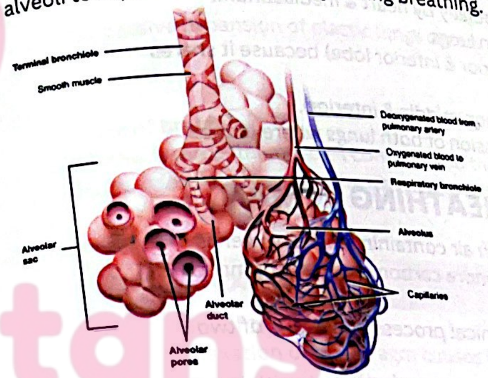
- There are over **700 million** alveoli present in the lungs.
- The wall of each alveolus is only **0.1 μm** thick.





**Composition of alveoli**
- Capillary Network
- Protein
  - Collagen
  - Elastin
- Squamous epithelium

- On its outside is a dense network of blood capillaries.
- Lining each alveolus is a moist squamous epithelium.
- This consists of very thin, flattened cells, reducing the distance over which diffusion must occur.
- Collagen and elastin proteins are also present in their walls which allow the alveoli to expand and recoil easily during breathing.




**SURFACTANT:**
- Alveoli of human lungs lined with surfactants, a film of lipoproteins.
- Lowers surfaces tension & prevents alveoli from closing.
- Speed up transport of $O_2$ & $CO_2$ between air & liquid lining the alveoli.
- Constantly being secreted & reabsorbed in healthy lungs.

| Components of Respiratory System | Cartilage | Ciliated epithelium with goblet cells | Smooth Muscles | Elastic Fibers |
|---|---|---|---|---|
| Trachea | ✔ | ✔ | ✔ | ✔ |
| Bronchi | ✔ | ✔ | ✔ | ✔ |
| Terminal Bronchitis | ✔ | ✔ | ✔ | ✔ |
| Respiratory Bronchiole | ✔ | ✔ | ✔ | ✔ |
| Alveolar Dust | ✔ | ✔ | ✔ | ✔ |
| Alveolar Sac | ✔ | ✔ | ✔ | ✔ |

## STRUCTURE OF LUNGS:

- Lungs lie within thoracic cavity, which is bounded by ribs & diaphragm.
- Closed sac connected to outside by way of trachea & nostrils or mouth.

- Placed in a chest cavity.
- Lungs are covered by double layered thin membranous sacs called pleura.
- The principal organ of respiration, & spongy is nature due to presence of millions of alveoli.

**PTB**

- The floor of chest is called **diaphragm** which is **sheet of skeletal muscles.**
- Pleural membranes are part of thoracic cavities containing lungs.

**FTB**

- Lungs are conical in shape with its base resting in diaphragm & its apex extends to point just above clavicle of **1st rib**.
- Right & left lungs separated medially by heart & mediastinum.
- Mediastinum is an area between lungs.
- Left lungs have two lobes (superior & inferior lobe) because it shares space with heart.
- The right lung has **3 lobes** (superior, middle & interior).
- Hilum is triangular shaped depression of both lungs where bloods vessels & airways pass into lungs.

## MECHANICS OF BREATHING IN MAN

- Breathing is a process in which fresh air containing more oxygen is pumped into the lungs and air with more carbon dioxide is pumped out of the lungs.
- In other words, breathing is a mechanical process consisting of two phases, inspiration and expiration.
- During **inspiration**, fresh air moves in and in **expiration** air with low $O_2$ and high $CO_2$ content moves out of the lungs.
- Lungs are spongy in nature. The lungs themselves neither pull air in nor can they push it out.
- The floor of the chest cavity is diaphragm, which is a muscular sheet and separate the thoracic cavity from the abdominal cavity.

**PTB**

- During rest breathing occurs rhythmically at a frequency of **15 to 20 times per minute.**
- Walls of chest cavity are composed of ribs and intercostal muscles.

**FTB**

- The diaphragm and the intercostal muscles accomplish the expansion and contraction of lungs.
- There are two sets of intercostal muscles between each pair of ribs: external intercostal muscles and internal intercostal muscles.
- The muscle fibers run diagonally but in opposite direction in the two sets of muscles.

## INSPIRATION



- It is taking in of air. During inspiration the space inside the chest cavity is increased in two ways.
- Firstly, the muscles of ribs contract and elevate the ribs upwards and forwards.
- Secondly, the muscles of diaphragm also contract, and diaphragm becomes less domelike.
- This downward movement of diaphragm and outward and upward movement of the ribs causes increase in the chest cavity and reduces pressure.
- When the pressure from the lungs is removed, they expand.
- With the expansion of the lungs vacuum is created inside the lungs in which the air rushes from the outside due to higher atmospheric pressure. This is called inspiration.

**PTB**

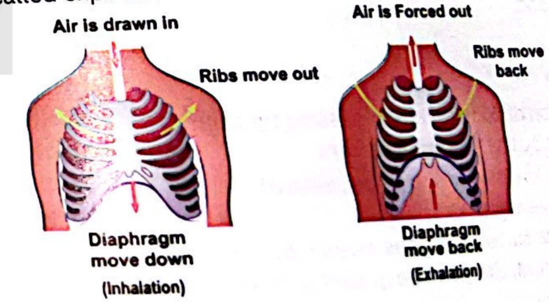
- During inspiration passive expansion of elastic lungs occurs.

**FTB**

- It is an active phase of breathing.
- During it the external intercostal muscles contract and the internal intercostal muscles relax which causes the rib cage to move forward and upward.
- The alveoli are inflated.

## EXPIRATION

- It is the removal of air out of the lungs.
- During expiration the relaxation of diaphragm causes it to become more dome shaped.
- During expiration the muscles of ribs are relaxed, and the ribs move downward and inward(backward).
- In this way from the sides of chest cavity the space becomes less.
- This reduction in space of the chest cavity exerts pressure on the lungs.
- The pressure in the thorax and the chest cavity is increased to more than the atmospheric pressure.
- When lungs are pressed the air inside the lungs move out of the lungs. This is called expiration.




**PTB**

- During [illegible] contraction of lungs takes place.

**FTB**

- It is a passive phase of breathing.
- Relaxation of external intercostal and contraction of the internal costal muscles causes the rib cage to move downward and backward.

## RESPIRATORY DISTRESS SYNDROME

- In Premature infant, respiratory distress syndrome is common, especially for infant with a gestation age of less than **7 months**.
- This occurs because enough surfactant (mixture of lipoprotein molecules produced by the secretary cells of the alveolar epithelium which forms a layer over the surface of the fluid within the alveoli to reduce the surface tension) is not produced to reduce the tendency of the lungs to collapse.

**PHASES OF BREATHING:**

| Features | Inspiration | Expiration |
|---|---|---|
| Another Name | Inhalation | Exhalation |
| Definition | Taking in of air into lungs | Removal of air out of lungs |
| Diaphragm | Contracts moves down, Becomes less dome-like | Relaxes, move up, Becomes more dome-like |
| Ribs-Muscles | Contract | Relax |
| Rib cage | Move upward, forward & outward | Moves downward, inward & backward |
| Change in lungs-volume | Increases | Decrease |
| Change in presence on lungs | Decreases | Increase |
| Air Moves | Into Lungs | Out of lungs |
| PTB Basic mechanism | Passive expansion of lungs occurs | Passive contraction of lungs take place. |
| FTB Nature | Active process, involving contraction | Passive process involving elastic recoil |
| External Intercostal muscles | Contracts | Relaxed |
| Internal intercostal muscles | Relax | Contracts |

## TRANSPORT OF RESPIRATORY GASES

Like other materials, respiratory gases are also transported in various regions of the body by means of blood.

**PTB**

Intake of oxygen and release of carbon dioxide by blood passing through capillaries of alveoli is brought about by the following factors

- Diffusion of oxygen in and carbon dioxide out occurs because of difference in partial pressures of these gases.
- Within the rich network of capillaries surrounding the alveoli, blood is distributed in extremely thin layers and, therefore, exposed to large alveolar surface.
- Blood in the lungs is separated from the alveolar air by extremely thin membranes of the capillaries and alveoli.





**FTB**

The blood transport oxygen from the lungs to different tissues and carbon dioxide from tissues to the lungs

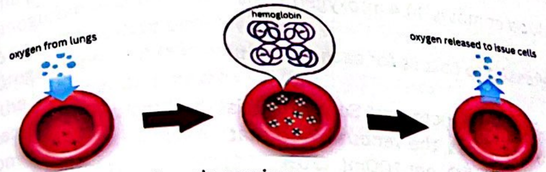
## TRANSPORT OF OXYGEN

- The respiratory pigment in the human body is called hemoglobin.
- It is contained in the red blood corpuscles.
- Haemoglobin readily combines with oxygen to form bright red oxyhaemoglobin at high partial pressure.

**AT LUNGS:**

1. Hb act as efficient O2 carries, facilitated by carbonic anhydrase enzyme present in RBCs.
2. A small proportion of oxygen also gets dissolved in the blood plasma.

$Hb + O_2 \quad HbO_2$




- Haemoglobin can absorb maximum oxygen at the sea level.
- The maximum amount of oxygen which normal human blood absorbs and carries at the sea-level is about **20ml/100ml** of blood.
- This is the maximum capacity of haemoglobin for oxygen when it is fully oxygenated.
- It is **100%** saturation achieved at **100mmHgPO₂.**

**PTB**

**At Aerobic Tissue:**

- Oxyhaemoglobin is unstable and splits into the normal purple-red coloured haemoglobin and oxygen in the conditions of low oxygen concentration and less pressure.

**Hb + O2Carbonic ouhydrase. Hb + O2**

- Under normal conditions, blood of alveoli of the lungs is not completely oxygenated.
- When an oxygen tension is **115mm** mercury, haemoglobin is **98** percent saturated and, therefore, contains **19.6** ml of oxygen per **100ml** of blood.
- This means that haemoglobin can be almost completely oxygenated by an oxygen pressure of **100 mm** mercury, which is present in the lungs.
- Any higher oxygen pressure would have the same result.
- When oxygen pressure falls below **60 mm** mercury, as in many cells and tissues, the oxygen saturation of haemoglobin decreases very sharply.
- This results in the liberation of large quantities of oxygen from

haemoglobin.
- In this way in the tissue where oxygen tension is low oxyhaemoglobin dissociates rapidly.

## SCUBA DRIVER

- As a scuba diver descends in the sea, the pressure of the water on his body prevents normal expansion of the lungs.
- To compensate, the diver breaths pressurized air from air cylinders, which has a greater pressure than sea level air pressure.

**FTB**

- The amount of hemoglobin is **15g/100ml** of blood. Since **1gm Hb** can combine with **1.34ml of $O_2$** so 100ml combine with **20ml of $O_2$.**
  **100ml = 15 × 1.34 = 20.1**
  Normally each **100ml** of arterial blood contain **19.4ml** of oxygen **(97% saturation at 95mmHg $PO_2$)**
- However, 100ml of venous blood contains **14.4 ml** oxygen **(75% saturation at 40mmHg).**
- This means that **5ml of $O_2$** is released to tissues for each **100ml** of blood.

During exercise the need for $O_2$ is greatly increased. So, more $O_2$ is released by the arterial blood to the issues, the venous blood that leaves the active tissue has only **4.4ml** of $O_2$ per 100ml. **(20% saturation at 18mmHg).**

## THROUGH PLASMA:

- $O_2$ is relatively insoluble in blood. Therefore, a small amount of $O_2$ is transported in dissolved state in plasma, normally each **100 ml** blood contain **0.29 ml of $O_2$ ($PO_2$ 95 mmHg)** & this capacity may increase up to **0.3ml/100 ml** of blood. In venous blood **0.12 ml** of dissolved $O_2$ **($PO_2$ is 40mmHg).**
- So, **0.17 ml of $O_2$** transported by each **100ml** of blood through tissues per cycle.

## FACTORS AFFECTING $O_2$ CARRYING CAPACITY OF HB

- The following factors affect the $O_2$ carrying capacity of Hb.

**Factors affecting $O_2$ carrying capacity of Hb**
- Carbon dioxide
- Temperature
- pH

## CARBON DIOXIDE

- When carbon dioxide pressure increases, the oxygen tension decreases, the capacity of haemoglobin to hold oxygen becomes less.
- In this way increased carbon dioxide tension favours the greater liberation of oxygen from the blood to the tissue.



**When CO2 pressure or tension increase than**
- Oxygen tension decrease
- $O_2$ holding capacity of Hb decrease
- Greater liberation of $O_2$ from blood to tissue

## TEMPERATURE

- Rise in temperature also causes a decrease in the oxygen-carrying capacity of blood, e.g., in the increased muscular activity.

## PH

- The pH of blood also influences the degree to which oxygen binds to haemoglobin
- As the pH of the blood declines, the amount of oxygen bound to haemoglobin also declines.
- This occurs because decreased pH results from an increase in hydrogen ions, and the hydrogen ions combine with the protein part of the haemoglobin molecules, causing a decrease in the ability of haemoglobin to bind oxygen.
- Conversely, an increase in blood pH results in an increased ability of haemoglobin to bind oxygen.
- Another factor that affects the $O_2$ carrying capacity of Hb is the partial pressure of $O_2$.

## TRANSPORT OF $CO_2$ IN BLOOD

- Carbon dioxide is more soluble than oxygen and dissolves freely in the tissue fluid surrounding the cells.
- From the tissue fluid, dissolved carbon dioxide passes to the plasma within the blood capillaries.
- Following are the ways by which $CO_2$ is transported through blood.

**Vehicles carrying $CO_2$**
- Carboxy haemoglobin
- Dissolved in plasma
- Bicarbonate ion
- Potassium ion

| Ways of transport of Co2 | |
|---|---|
| 20% | Carboxyhemoglobin / carbaminohemoglobin |
| 5% | Plasma protein (Mostly Albumin) |
| 70% | Bicarbonate ions combined with sodium in plasma |
| 5% | Dissolved in plasma |
| Small Amount | By corpuscles combined with potassium |

## AS BICARBONATE IONS

- **About 70%** carbon dioxide is carried as bicarbonate ion combined with sodium in the plasma.
- As carbon dioxide from tissue fluid enters the capillaries it combines to form carbonic acid in the presence of **enzyme carbonic anhydrase.**

$$CO_2 + H_2O \rightarrow H_2CO_3$$

- The carbonic acid splits quickly and ionizes to produce hydrogen ions and bicarbonate ions.

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

**PTB**

- When blood leaves the capillary bed most of the carbon dioxide is in the form of bicarbonate ions.
- All these reactions are reversible. In the lungs bicarbonate ions combine with hydrogen ions to form carbonic acid which splits into water and carbon dioxide.
- It is this carbon dioxide which diffuses out from the capillaries of the lungs into the space of alveolar sac.

$$HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow CO_2 + H_2O$$

## $CO_2$ AS A REGULATOR OF BREATHING

- Carbon dioxide which is much more important than oxygen as a regulator of normal alveolar ventilation (Breathing) but under certain circumstances a reduced **PO2** (partial pressure of the oxygen) in the arterial blood does play an important stimulatory role especially during conditions of shock.

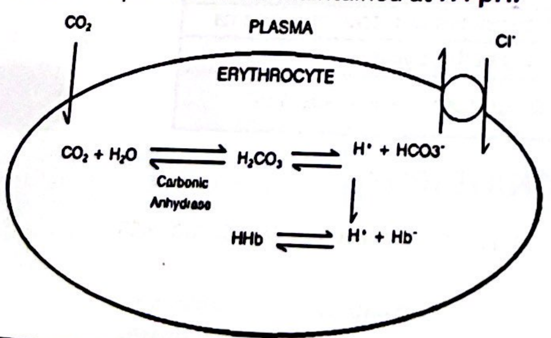
**FTB**

- The continuous breakdown of $H_2CO_3$ led to accumulation of $H^+$ which increases the acidity of blood or pH of system decrease. Here oxyhemoglobin acts as a buffer & readily associate H to form hemoglobinic acid.

$$Hb4O_2 + H^+ \rightarrow HHb + 4O_2$$

## CHLORIDE SHIFT OR HAMBURGER'S PHENOMENA

- From RBCs $HCO_3$ ions diffuse into plasma. The negative charge is balanced by the diffusion of Chloride ion in the opposite direction.
- This is achieved by special bicarbonate carrier proteins which exist in the membrane of RBC.
- The protein moves the two ions into the opposite direction maintaining the balance of ions on either side. This is called chloride shift or Hamburger' phenomenon.
- The $Cl^-$ that enters the RBCs combines with $K^+$ to form KCl whereas bicarbonate in plasma, react with Na to form sodium bicarbonate. By this mechanism the pH of blood is maintained at **7.4 pH.**






## PARTIAL PRESSURE OF $CO_2$:

- The transport of $CO_2$ depends upon partial pressure of $CO_2$.
- When the partial pressure of $CO_2$ is higher in the tissues than blood then more & more carbonic acid forms.
- But when the partial pressure of $CO_2$ is higher in blood than tissues, then $CO_2$&$H_2O$ are released.

## PARTIAL PRESSURE OF $CO_2$:

- Some of the carbon dioxide is carried as carboxyhaemoglobin.
- $CO_2$ has a greater affinity with the globin part of haemoglobin.

**PTB**

- Carboxyhaemoglobin is formed when carbon dioxide combines with amino group of haemoglobin
- About **20% $CO_2$** is carried in this way.

**FTB**

- However, the reaction depends upon partial pressure of $CO_2$. When partial pressure is higher in tissues than blood formation of carboxy hemoglobin occurs.
- But when partial pressure of $CO_2$ is higher in blood as compared to tissues as in lungs $CO_2$ is released by hemoglobin by breaking bound with Hb.

## AS DISSOLVED $CO_2$ IN PLASMA

- It is considered an efficient way to carry $CO_2$.

**PTB**

- Other plasma proteins also carry about **5% carbon dioxide** from the body fluids to the capillaries of lungs.

**FTB**

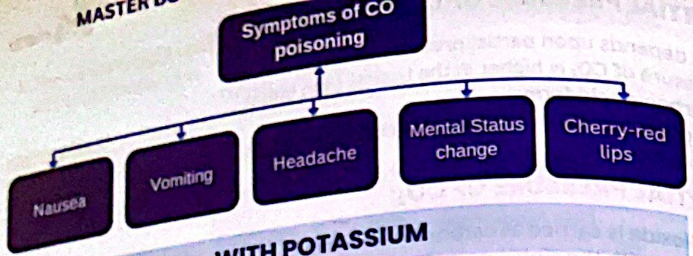
- Only **7% of $CO_2$** is carried through plasma.

## $CO_2$ POISONING

- Gases that have undergone incomplete combustion produce CO and toxic fumes (hydrogen cyanide).
- In carbon monoxide poisoning caused by gas heaters left on overnight in closed environments CO binds to hemoglobin preventing the uptake of oxygen by hemoglobin.

## SYMPTOMS OF CO POISONING

- CO binds hemoglobin with an affinity **249 times** greater than that of oxygen.
- CO poisoning also decreases the ability of hemoglobin to release oxygen to tissue




## WITH POTASSIUM

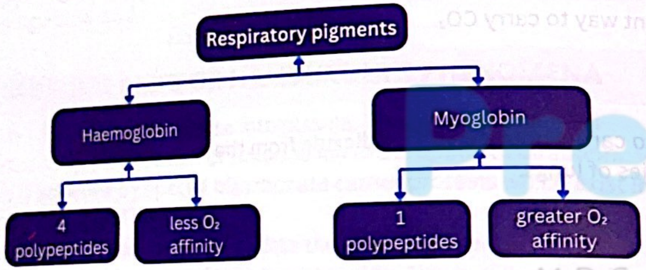
- Small amounts of carbon dioxide are also carried by corpuscles combined with potassium.

## CARBON DIOXIDE CONCENTRATION IN ARTERIAL AND VENOUS BLOOD

**PTB**

- It has been found that arterial blood contains about **50 ml** of carbon dioxide per **100 ml** of blood whereas venous blood has **54 ml** of carbon dioxide per **100 ml** of blood.
- In this way each **100 ml** of blood takes up just **4 ml** of carbon dioxide as it passes through the tissues and gives of **4 ml** of carbon dioxide per **100 ml** of blood as it passes through the lungs.

## ROLE OF RESPIRATORY PIGMENTS




- Respiratory pigments are colored molecules which act as oxygen carriers.
- Various types of respiratory pigments are present in different animals. The pigment combines with oxygen reversibly and increase the oxygen carrying capacity of the blood.
- The two well-known respiratory pigments are:
  1. Hemoglobin
  2. Myoglobin

**FTB**

All known respiratory pigments contain a colored non-protein portion e.g., haem (heme) in hemoglobin.

## HAEMOGLOBIN





- It contains **4 globin protein chains**, each associated with haem, an iron-containing group.
- Iron combines loosely with oxygen, and in this way, oxygen is carried in the blood.
- At high oxygen concentration, the pigment combines with oxygen, whereas at low oxygen concentrations the oxygen is quickly released.

**PTB**

- It increases the $O_2$ carrying capacity in man up to **75 times**.

## MYOGLOBIN

- Myoglobin consists of just one polypeptide chain associated with an iron containing ring structure which can bind with one molecule of oxygen.
- It is found in skeletal muscles fibers, and this is the main reason why meat appears red.
- It serves as an intermediate compound for the transfer of oxygen from haemoglobin to aerobic metabolic processes of the muscle cells.

**PTB**

- The affinity of myoglobin's to combine with oxygen is much higher as compared to haemoglobin.

**FTB**

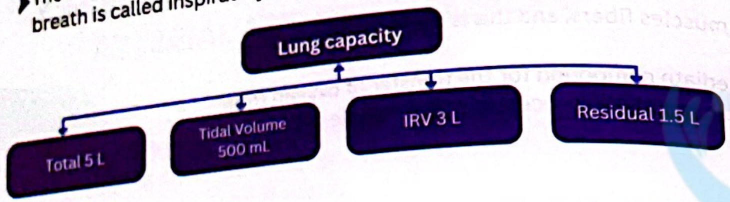
- Myoglobin releases oxygen when the partial pressure of oxygen is below **20mmHg**.
- In this way, it stores oxygen in resting muscle, only releasing it when supplies of oxyhaemoglobin have been exhausted.

| Haemoglobin | Myoglobin |
|---|---|
| Consists of four polypeptide chains | Consists of one polypeptide chain |
| Possesses four iron containing haem groups | Possesses one iron containing haem group |
| Can bond loosely to four O2 molecules through iron of haem | Can bind to only one O2 molecule through iron of haem. |
| Found in muscles | Found in RBCs |
| Transports Oxygen | Stores Oxygen |
| Has less affinity with oxygen | More affinity with oxygen |
| Loses oxygen at PO2 60mm Hg | Loses oxygen at PO2. 20mm Hg |

| Property | Vertebrate | Invertebrate |
|---|---|---|
| Pigment | Haemoglobin | Haemocyanin (in molluscs)<br>Haemoerythrin (in some marine animals)<br>Chlorocruorin (in annelids) |
| Color when oxygenated | Bright red | Haemocyanin (blue)<br>Haemoerythrin (violet to pink)<br>Chlorocruonin (green) |
| Color when deoxygenated | Dark red | All become colorless |

## LUNG CAPACITIES

- Breathing (inspiration and expiration) occurs in a cyclical manner due to the movements of the chest wall and the lungs.
- The resulting changes in pressure, causes changes in lung volumes, i.e., the amount of air the lungs are capable of occupying.
- These volumes tend to vary, depending on the depth of respiration, gender, age and in certain respiratory diseases.
- Respiratory volume is the amount of air inhaled, exhaled and stored within the lungs at any given time.
- The amount of air which is inhaled or exhaled at rest is called tidal volume.
- The amount of extra air inhaled (above tidal volume) during a deep breath is called inspiratory reserved volume.

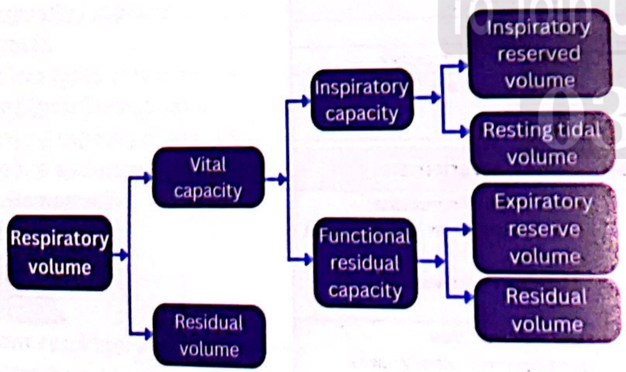



**PTB**

- In an adult human being when the lungs are fully inflated the total inside capacity of lungs is about **5 litres.**
- Normally when we are at rest or asleep the exchange is only about half a litre.
- The volume of air taken inside the lungs and expelled during exercise is about **3.5 litres**. In other words, there is a residual volume of **1.5 litres** even during exercise which cannot be expelled.

**FTB**

- The average tidal volume is **500ml**. The inspiratory reserved volume can be as high as **3000ml**.
- The total lung capacity of humans is **6000ml**.





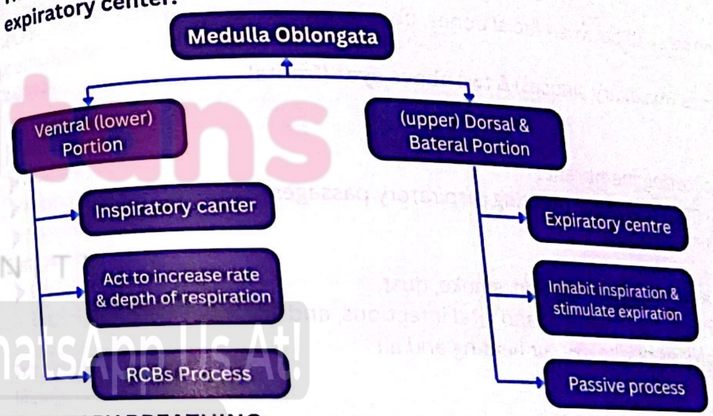

## BREATHING RATE

- Normally, at rest we inhale and exhale **15-20 times per minute.** During exercise the breathing rate may rise to **30 times per minute.**
- The increased rate and depth of breathing during exercise allows more oxygen to dissolve in blood and supplied be to the active muscles.
- The extra carbon dioxide which the muscle puts into the blood is removed by deep and fast breathing.
- There is a little change in the composition of inhaled and exhaled air during rest or exercise in most of the constituents of the air.

| Gas | Inhaled% | Exhaled% |
|---|---|---|
| Oxygen | 21 | 16 |
| Carbon dioxide | 0.04 | 4 |
| Water vapours | Variable | Saturated |
| Nitrogen | 79 | 79 |

## CONTROL OF BREATHING

- Normally breathing is an involuntary process but some voluntary control is also possible.
- Involuntary control of breathing is done by Medulla oblongata.
- **The ventral portion (lower)** of breathing center acts as **inspiratory center.**
- **The dorsal (upper)** and lateral portions of breathing center act as **expiratory center.**




### VOLUNTARY BREATHING:

- Sometimes as is evident by the ability to hold breath, breathing becomes voluntary and is under the control of the Cerebral hemisphere (cerebral cortex)
- During emotional damage breathing is under the control of the limbic system.

**FTB**

**Hiccups:**

- Spasmodic contraction of diaphragm while glottis is closed.
- Producing sharp respiratory sound.
- Reflexive & serves no known functions.

**Sneezing:**
- Deep inspiration followed by closure of glottis.
- Forceful expiration results abruptly opens glottis, sending blast air through nasal cavity, eyelids, close reflexively.
- Reflexive response to irritating stimulus of nasal mucosa.
- Clear the upper respiratory passages.

**Snoring:**
- Rough, raspy noise that can occur when sleeping person inhales through mouth & nose.
- Noise is usually made by vibration of soft palate.
- Vocal cord vibrates.

# DISORDERS OF THE RESPIRATORY SYSTEM:

Continuous inhalation of harmful substances results in respiratory disorders.

## UPPER RESPIRATORY TRACT INFECTION

It Includes
1. Sinusitis 2. Otitis media

### SINUSITIS

"Inflammation of nasal sinuses"
- May be acute (symptoms last **2-8 weeks**) on chronic (symptoms last much longer).
- Sinuses are holes in the skull between facial bones, (four large sinuses).
- Two inside cheekbones (maxillary sinuses) & two above eyes (frontal sinuses).

**Function of Sinus:**
- Lined with mucous secreting membrane.
- Secrete antibody rich mucus while protecting respiratory passages from irritation in the airs we breathe

**Causes of sinusitis:**
- Cold and wet climate, atmospheric pollution, smoke, dust, overcrowding, dental infections, bacterial and viral infections, and dryness in homes and offices due to dry-air heating and air conditioning systems.

**Symptoms:**
- It includes Fever, Nasal obstruction, Raspy voice, Pus-like nasal discharge, Loss of sense of smell, Facial pain, Headache

**Treatment:**
- If bacterial infection is present, antibiotics or supha drugs are prescribed.
- Nebulization

### OTITIS MEDIA

It is an inflammation of the middle ear in which EUSTACHIAN TUBE (tube between middle ear and pharynx) filled with fluid and become close.
- If this fluid is not clear up after three months or more, then it becomes **chronic otitis media**.





**Causes:**
- Infection, Allergy, Recurrent attacks of common cold, Blockage of Eustachian tube, Nutritional deficiency, Sinusitis, Measles

**Symptoms:**
1. Sudden and severe earache
2. Deafness
3. Fever
4. Headache
5. Sense of fulfilness of ear
6. Tinnitus (ringing or buzzing in the ear)
7. Fluid leaking from ear
8. Difficulty in speaking and hearing
9. Sometimes eardrums can burst, which causes a discharge of pus and relief of pain

**Treatment:**
- Mostly **80%** patients are treated by clearing fluid within **3-4 days**.
- Complicated cases require antibiotic

## LOWER RESPIRATOTRY TRACT INFECTIONS

It includes:
1. Pneumonia
2. Lung cancer
3. Pulmonary Tuberculosis
4. Emphysema

### PNEUMONIA

Pneumonia is characterized by inflammation of alveolar wall and accumulation of fluids and pus in alveolar sacs.

**Causes:**

1. **Bacterial genra such as**
- Streptococcus pneumoniae
- Staphylococcus aureus
- Haemophilus influenza
- Mycoplasma

**Symptoms**
- Chills, chattering teeth, sweating due to high fever, chest pain, increased pulse rate, difficulty breathing, violent coughing, bluish colour of lips, red or rusty-brown coloured sputum.

**Treatment:**
Mostly antibiotic treatment.

### LUNG CANCER

Cancer is malignant tumour which may develop due to uncontrolled cell division.

**Causes:**
- Smoking is the main cause of lung cancer.
- Asbestos
- Arsenic
- Gamma radiations
- X-rays
- Carcinogens

**Symptoms**
- Thickening and callusing of the cells in the lining of bronchi

- Loss of cilia that make it impossible toto prevent dust and dirt from entering

**Treatment:**

- **PNEUMONECTOMY** Removal of the infected lobe before secondary growth starts
- Chemotherapy and radiotherapy

## PULMONARY TUBERCULOSIS

It is highly infectious chronic bacterial infection of the lungs. The alveoli burst and are replaced by inelastic tissues.

**Causes:**

- *By Mycobacterium tuberculosis*

**Symptoms**

- Low-grade fever, night sweats, weight loss, anorexia, depression, weakness and dry cough with sputum, inflammation of pleura, dull ache in the chest.

**Treatment:**

Taking medicine for regularly **9 months** can cure it. This is called **DAILY OBSERVED TREATMENT SHORT COURSE (DOTS).**

## EMPHYSEMA

A lung disorder in which the alveoli (AIR SACS) degenerate and the elastic fibres present in them are destroyed. The small alveoli combine to form a large alveolus with and increased volume and less air exchange surface area.

**Causes:**

- Long term irritation of lungs by cigarette smoke, polluted air or industrial dust and exposure of lungs to certain drugs

**Symptoms**

- Increasing breathlessness
- Difficulty in walking
- Lung loose elasticity
- Difficulty exhaling
- Inflammation and narrowing of bronchioles
- Cyanosis

**Treatment:**

There is no treatment but following can be helpful:

- Avoid smoking
- All kinds of respiratory infections should be treated
- Oxygen equipment and respiratory devices are helpful



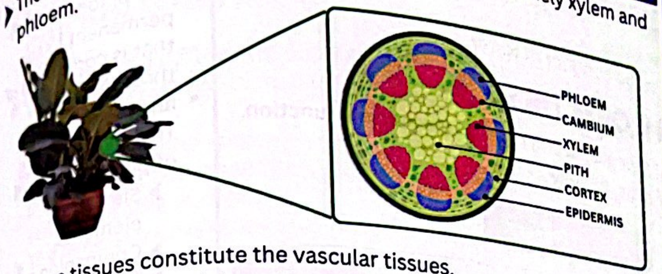


CHAPTER 10

# TRANSPORT

## TRANSPORT IN PLANTS

- There are **two types** of conducting tissues in plants, namely xylem and phloem.

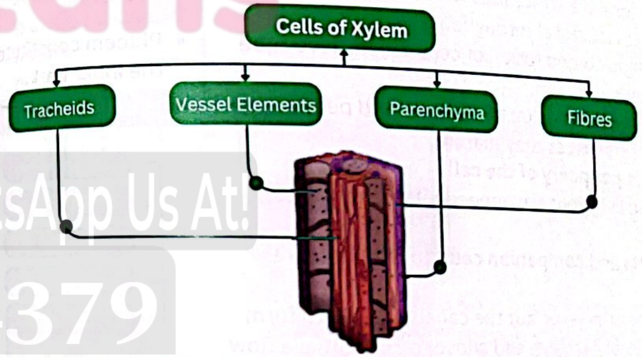



- These tissues constitute the vascular tissues.
- **Xylem** conducts mainly water and minerals from the roots up to other parts of the plants.
- **Phloem** conducts organic food from the leaves both up and down the plant.

## XYLEM TISSUES

**FTB**

- Xylem Tissues Beside conduction these tissues are also used for support.
- It consists of **four cell types;**




- Tracheids are **single cells**, which are **elongated, tapering** and **lignified**. They have mechanical strength and give support.
- Tracheids function very efficiently, **e.g.** conifers rely exclusively on tracheids for the transportation of water.
- In angiosperms relatively there are **fewer tracheids than vessels**.
- Vessels are more effective structures for transportation, which are needed by angiosperms for **high rates of transpiration** in the group.
- Xylem vessels are the **conducting units** of angiosperms.
- These are very long, tubular structures formed by the fusion of several vessel cells (vessel elements) end to end in a row.
- Vessels are shorter than tracheids and act as the pipeline.

**BTB**

- The word xylem is derived from Greek word **'Xylon'** meaning wood.
- These are elongated cells and tubular water transport system because they are connected **'end to end'** with each other.
- Tracheids are elongated cells up to **80nm** wide.
- Mature Tracheids are dead and hence the protoplast is lost.

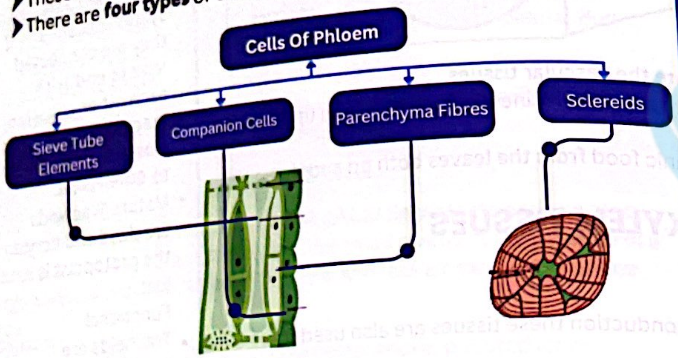
Functional

- Tracheids are surrounded by **supporting** and **storage cells, parenchyma, sclereids** and **fibres.**
- Vessel elements are **wider, shorter, thinner** and **less tapered** than tracheids.
- Vessel elements are **individual cells** linked end to end forming xylem vessel.

- Xylem parenchyma occurs in both **primary** and **secondary xylem**. It is more extensive and important in secondary xylem. The functions of xylem parenchyma include **food storage, deposition of crystals, radial transport of food** and **water and gaseous exchange** through the intercellular spaces.
- Xylem fibres are originated from tracheids. They are **shorter** and **narrower** than tracheids
- They have much **thicker walls.**
- They are **not involved** in the conduct of water.

## PHLOEM TISSUES

- These are composed of **living cells** and have **no mechanical function.**
- There are **four types** of cells, namely:




- **Sieve tubes** are the long tube like structures, which translocate solutions of organic solutes (sucrose) throughout the plant.
- These are formed by the end-to-end fusion of cells called **sieve tube elements** or **sieve elements**.
- **Sieve tube elements** have walls made up of cellulose and pectic substances but the nuclei are lost as they mature.
- The cytoplasm confined to **periphery of the cell.**
- The sieve elements remain living but are dependent on the adjacent companion cells.
- The two, i.e. **sieve elements** and **companion cells**, together form a **functional unit.**
- Plasmodesmata run through the walls but the canals enlarge to form pores, making the walls look like a sieve and allosolute potential a flow of solution from one element to the next.

## MOVEMENT OF WATER

- Transport or movement of materials in between the organisms and their environment, as well as the transport of materials in various parts of a living organism is vital event, which determines the overall life activities of the organisms.
- In plants all their required substances (except light and carbon dioxide) are supplied through soils by the roots.
- The water, carbon dioxide and different mineral nutrients are used by the plants and are converted into energy rich organic food like

**BTB**

- The phloem tissue is present on outside of xylem tissue
- The phloem is a permanent tissue that is composed of three living cells and one dead cell. The LIVING CELLS of phloem are:
  - Sieve tube elements
  - Companion cells
  - The phloem parenchyma
- The DEAD CELL is SIEVE TUBE.
- The end walls of sieve tubes are perforated and are composed of 'cellulose'.

**KPK**

- Phloem constitutes the inner bark.

**5 cells of Phloem**
- Parenchyma
- Phloem fibres
- Companion cells
- Sieve tube cells
- Phloem ray cells

**BTB**

The movement of water between plant cells and their environment takes place by osmosis.

- **Endosmosis:** if water moves into the cell by osmosis





carbohydrates, lipids and proteins by the universal phenomenon of photosynthesis.

- In this process the **source of energy** is sun.
- **Diffusion** is the movement of substances in the form of molecules or ions from the regions of their higher concentrations to the regions of their low concentrations.
- It is the basis of transportations in all types of living organisms.
- This process is **deadly slow** so it may not be used alone as transporting means.
- **Osmosis** is the diffusion of water through living membranes. The special nature and structure of cell membranes makes the process very efficient.
- Osmosis is the phenomenon of movement of water from its high potential (high conc.) to the region of low potential through a semipermeable membrane.
- The mineral nutrients are transported in dissolved form.
- In living organisms the transport of materials is in the form of solutions so the phenomenon may be defined as the movement of water from hypotonic solutions (dilute solutions) to the regions of hypertonic condition through a semipermeable membrane.
- The movement will continue until an equilibrium is maintained.
- At this level the two solutions across the membrane are called **isotonic**.
- The plant as a whole and the individual cells get water and other substances by several other means besides diffusion and osmosis.
- **Plasmolysis** can be defined as the shrinkage of the protoplasm of a cell due to exosmosis when it is placed in hypertonic solution. The cell in this condition is called **plasmolysed**. However if a plasmolysed cell is placed in a hypotonic solution the cell attains its normal state i.e, it becomes turgid again. The phenomenon is called **deplasmolysis** and occurs due to endosmosis.

## UPTAKE OF WATER BY ROOTS AND PATHWAYS

**Pathways For Movement**
- Apoplast Pathway
- Symplast Pathway
- Vacuolar Pathway

- The cell wall of epidermal cells of roots is freely permeable to water and other minerals.
- The cell membrane is differentially permeable.
- From root hairs water enters the epidermal cells by osmosis. The water moves along the concentration gradient. It passes through cortex, endodermis, pericycle and reaches the xylem vessels.
- There are three pathways taken by water to reach the xylem tissues

- **Exosmosis:** If water moves out of the cell by osmosis.

**BTB**

- The root hairs are located on the edge of the roots while xylem vessels are in the centre.
- **APOPLAST** is the extra cellular pathway between the cell walls of adjacent cells.
- The ions easily reach the endodermis by apoplast pathway, but the casparian strips prevent further movement.
- **CASPARIAN STRIP** is a band of cell wall material deposited in the radial and transverse walls of root endodermal cells. It is chemically composed of **suberin** (a water proof waxy substance).
- **SYMPLAST PATHWAY** works through plasmodesmata which are cytoplasmic microscopic channels between cell walls of adjacent cells.
- **VACUOLAR PATHWAY:** encounters hig[h] resistance and aresult little fl[ow] usually occur[s]

## APOPLAST PATHWAY

- The apoplast is the system of **adjacent cell walls** which is continuous throughout the plant.
- When water moving through spaces in the cell walls reaches the endodermis, its progress is stopped by **casparian strips**, (a band of suberin and lignin bordering four sides of root endodermal cells).
- Therefore water and solutes particularly salts in the form of ions must pass through the cell surface and into the cytoplasm of the cells of the endodermis.
- In this way the cells of the endodermis can control and regulate the movement of solutes through the xylem.

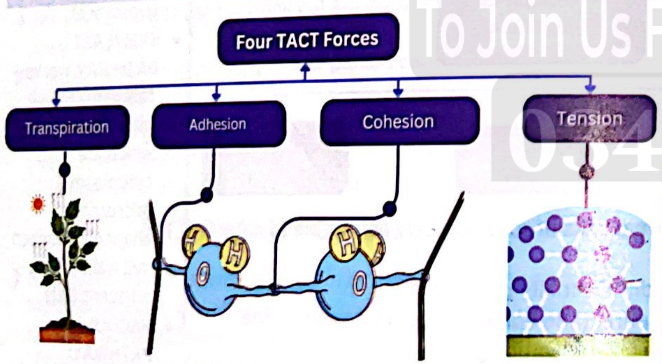
## SYMPLAST PATHWAY

- Movement of cell sap that involves **cytoplasmic connection** of adjacent cells is termed as symplastic transport or pathway.
- The symplast is the system of **interconnected protoplast** in the plant.
- The cytoplasm of neighboring protoplast is linked by the **plasmodesmata**, the cytoplasmic strands which extend through pores in adjacent cell walls.
- Once water and any solutes it contains is taken into the cytoplasm of one cell it can move through the symplast without having to cross further membranes.
- Movement might be aided by cytoplasmic streaming. The symplast is an important pathway of water movement.

## VACUOLAR PATHWAY

- In the vacuolar pathway water moves from vacuole to vacuole through neighbouring cells, crossing the symplast and apoplast in the process and moving membranes and tonoplast by osmosis.
- It moves down a water potential gradient.

### ASCENT OF SAP




- Once water and mineral enter the root xylem, they still must be moved to the leaves of the plant
- **Four important forces** combine to transport water solution from the roots through xylem elements and into the leaves.

making this pathway **less efficient.**

**KPK**

- Water not only translocate along the non-living cell walls and intercellular spaces but also moves inward across the living cortical cells by the process osmosis.
- Such a living medium transport is called **Symplast pathway**.
- A combination of adhesion, cohesion and surface tension **allow water to climb** the walls of small diameter tubes like xylem. This is called **capillary water** to The U-shaped surface it climbs the walls of the tube is called a **meniscus.**

**BTB**

**SAP:** Water and dissolved minerals are collectively called sap.
**ASCENT OF SAP:** The pull of water and dissolved minerals through the xylem tissue towards the leaves is known as ascent of sap.
**TRANSPIRATION:** involves the pulling







## TRANSPIRATION

- The loss of water vapours by evaporation from aerial parts of the plants is called **transpiration.**
- When stomata are open the water molecules move from high potential of water (inside the cells) to a region of low potential (in the air).

## ADHESION

- Adhesion is the attractive force between water molecules and other substances. Because both water and cellulose are polar molecules so there is a strong attraction for water within the hollow capillaries of the xylem.
- Adhesion of the string of water molecule to the wall of the xylem cells assists upward movement of the xylem sap counteracting the downward gravity. Adhesion also helps hold water in the xylem when transpiration is not occurring.

## COHESION

- Water is a polar molecule, with the oxygen carrying a slight negative charge while the hydrogen carry a slight positive charge.
- As a result, nearby water molecules attract one another, forming weak hydrogen bonds.
- The network of individually weak hydrogen bond within water collectively produces a very high cohesion.
- The column of water molecule within the xylem is at least as strong and as unbreakable as a steal wire of the same diameter.
- "Hydrogen bonds among water molecules provide the cohesion that holds together the 'string' of water extending the entire height of the plant within the xylem."
- Supplementing the cohesion between water molecules is adhesion between water molecules and the walls of xylem tubes help the water move upward, just as water is pulled up into a very narrow glass tube. This principle, called capillary action.
- This helps water move upward within xylem. The U shaped surface formed by water as it climbs the walls of the tube is called meniscus.

## TENSION

- Before a water molecule can leave the leaf, it must break off from the top of the string.
- In effect, it is pulled off by a large diffusion gradient between the moist interior of the leaf and the surrounding air.
- Cohesion resists the pulling force of diffusion gradient, but it is not strong enough to overcome it.
- The molecules break off, and the opposing forces of cohesion and transpiration put tension on the rest of the molecular string.
- As long as transpiration continues, the string is kept tense and is pulled upward as one molecule, exits the leaf and one right behind it is tugged up into its place.
- Tension is a negative pressure, a force that pulls water from locations

of water upward by utilizing the 'energy of evaporation'.

**KPK**

- Water has unusually high cohesive forces.
- It is estimated that water's cohesive forces inside xylem gives it a tensile strength equivalent to that of a **steel wire** of similar diameter.

**BTB**

- Transpiration provides the energy for tension.
- The hydrogen bonds produces this tension.

**KPK**

- High pH favours the activity of enzyme **'phosphorylase'** which converts starch to glucose and phosphate.
- It dissolves in the medium and and increases the concentration of cell sap.
- This causes and increase in the osmotic pressure of the guard cells
- The diffusion pressure deficit (DPD) also increases which results in movement of water into the guard cells from surrounding cells.

where the water potential is greater.

- The bulk flow of water to the top of a plant is driven by solar energy since evaporation from leaves is responsible for transpiration pull.

## OPENING AND CLOSING OF STOMATA

There are two hypothesis which may explain the opening and closing of stomata:

- Starch sugar hypothesis
- Influx of K Ions hypothesis

## STARCH SUGAR HYPOTHESIS

- It was proposed by German botanist H. Van Mohl. The guard cell absorbs $CO_2$.
- Some $CO_2$ reacts with water in which it is dissolved to form carbonic acid.
- In the presence of light energy, carbonic acid in the guard cell is converted into CO, and water, which are rapidly used in the synthesis of carbohydrates.
- The contents of illuminated guard cell are: **(i)** The acid concentration is low **i.e.** pH is high. **(ii)** Sugar concentration is high.
- As sugar concentration increases in the guard cells, as a result water enters the guard cells.
- The guard cells become turgid (swollen with water).
- The thin outer walls bulge out and force the inner thick wall into a crescent shape.
- In this way a stoma or pore is formed between each pair of guard cell.

## CLOSING OF STOMATA

- In the dark, most of the sugar molecules are removed by respiration or are converted into insoluble starch.
- So there is an increase in the acidity of the cell contents.
- As sugar molecules are removed from the guard cell and the relative concentration of water in the guard cell increases, water molecules diffuse out to the epidermal cells.
- As the guard cell loses water, it becomes flaccid. In contrast to turgidity, the loss of water causes them to become weak limp and soft.
- This condition is known as flaccidity and the cells are said to be flaccid.
- The inner thick wall moves together until the pore between them is closed.
- Closing of stomata prevents **(i)** loss of water vapour **(ii)** the entry of $CO_2$, into the leaf.
- The $CO_2$, produced during respiration is used for photosynthesis even though the stomata are closed.

## INFLUX OF $K^+$ IONS HYPOTHESIS

- The $K^+$ ion concentration in guard cells increase many times depending upon plant species.
- $K^+$ions enter guard cells from the surrounding epidermal cells by active transport.
- The accumulation of $K^+$ decreases the osmotic potential of guard cells.

- DURING NIGHT: Carbon dioxide level is high in stomata which causes a decrease in pH.
- Low pH converts glucose back into starch under the activity of phosphorylase. It causes the dilution of sap and a decrease in DPD.

**KPK**

**K+ INFLUX:**

- In presence of light starch is converted to phosphorylated hexoses which are then converted to **phosphoenol pyruvic acid.**
- The phosphoenol pyruvic acid combines with carbondioxide to produce **malelc acid.**
- The maleic acid is converted to **malate ion** and H+ ion.
- The H+ ions are transported to epidermal cells and K+ions are taken by the guard cells.
- The K+ and malate ions increases the concentration of sap in the guard cells, allowing water to move inward and cause turgidity.





- Water enters the guard cell by osmosis. The guard cells become turgid and are stretched and stomata are opened.
- The guard cells remain in this condition only so long as the pumping of $K^+$ ions into the cell is continued.
- So for keeping the stomata open a constant expenditure of energy is required.
- In darkness $K^+$ ions move out of the guard cells into surrounding epidermal cells.
- The water potential of the guard cells increase as a result water moves out of the cells.
- The loss of pressure makes the guard cells change their shape again and stomata closes.
- Level of $CO_2$, decreases in the spaces inside the leaf and light controls the movement of $K^+$ into and out of guard cells.
- A low level of $CO_2$, favours opening of the stomata and thus allow an increased $CO_2$, level and increased rate of photosynthesis.

## TRANSLOCATION OF ORGANIC MATTER

- Phloem tubes are delicate structures. These tubes are punctured by a small greenish insect, aphid during its feeding from the young shoots of a plant.
- Aphids are fluid (phloem) feeders. They suck sugary substance from phloem tissues. Biologists found that if the feeding aphid is removed by surgery and its style (pointed, tubular mouth part) is allowed to remain intended in the phloem tube. The phloem contents are continued to come out. On examining the contents it is found that it contains upto 30 percent sugars (sucrose), remaining 70 percent is water.
- Excess sugar is released as a drop of honey- dew that serves as food for ants.
- The sap in the phloem enters the insect's mouth parts under pressure.

**FTB**

- With the use of radioactive carbon dioxide during photosynthesis the path of the photosynthate may be traced.
- Biologists by conducting several of such experiments discovered that sugar flow involves a mass movement of phloem fluid based on bulk flow the movement of fluid from an **area of high pressure (source) to an area of low pressure (sink)**.
  The plant physiologists suggest that sugars produced in source regions, such as photosynthesizing leaves or storage places are loaded into the phloem's sieve tube elements by the companion cells.
- The active transport increases the concentrations of sugars in the phloem.
- As a result water moves to phloem by osmosis from the nearby xylem cells and increases turgor pressure in the phloem cells, which pushes forcibly the sugary solution away from the leaf (source).
- Meanwhile the root cells absorb the organic solutes from the phloem, making the phloem solution **hypotonic** and so the water from the phloem moves back to the xylem tubes.

**BTB**

- **SOURCE:** The part of plant from which sucrose and amino acids are translocated (green leaves and stem)
- **SINK:** The part where sucrose and amino acids are being translocated (yellow leaves, fruits, seeds and roots.)
- **PHLOEM SAP:** 10-25% of phloem sap is dry matter.90% of this matter is sucrose .While remaining are the organic molecules like proteins and lipids.

**KPK**

- The bulk flow of water to the top of a plant is driven by solar energy since evaporation from leaves is responsible for transpiration pull.
- Green leaves are regarded as **"source of assimilates"** because these are the sites of stomat closes.
- The underground stems are togeth called **"sinks of assimilates"**. They utilize and store food.

- Sugar is actively loaded into the sieve tube by osmosis.
- At the sink, the sugar is actively unloaded and water leaves the sieve tube by osmosis.
- The pressure gradient from source to sink. causes translocation from the area of higher hydrostatic pressure (the source) to the area of lower hydrostatic pressure (the sink)
- By studying carefully the whole mechanism it may be concluded here that the water pressure and the loading activities of companion cells provide the base for the movement of sugars, amino acids and a few mineral ions from sources to sinks.
- In a plant the same organ may be a source at one time and at some other time it may act as a sink e.g. beetroot.

**PTB**

- The processes involved for getting materials into and out of the cells are diffusion, facilitated diffusion, osmosis, active transport, endocytosis, exocytosis etc.
- In animals, the materials move into, within and out of the body, in respiratory circulatory, digestive and excretory systems
- In plants the processes of respiration, transportation, photosynthesis, absorption by roots, conduction of water, and the nutrients are involved in movement of the materials into, within and out of the body.

## NEED FOR TRANSPORT OF MATERIALS

- The living organism is a complex of interactions of physical and chemical reactions involving different elements and molecules.
- All living cells or living organisms, must obtain and transport certain materials within the body and also transport and remove the wastes out of their bodies or cells.
- If there were no transport systems, most of the cells of the body of a complex multicellular organism, would not be able to get the required materials and dispose of their wastes.
- **There are no mass flow systems in unicellular organisms** and lower multicellular organisms.
- The roots of a plant not only anchor the plant body in the soil, but also absorb minerals and water from the soil.
- There are **three types of nutrients** needed by the plants, carbon dioxide, water and minerals besides light to carry out photosynthesis.
- A rye plant less than one meter tall has some **14 million branch roots** of a combined length of over **600 kilometers.**
- To get these materials, roots must provide large surface area for absorption, which is achieved by extensive branching.
- The roots bear a dense cluster of tiny hair like structures which are extensions of epidermal cells of roots.
- These are the root hairs, which are in fact the sites where most of the uptake of water and minerals takes place.
- Plants are able to sythesize all their required compounds, with the help of the minerals and $H_2O$ from soil, $CO_2$ from air, and light energy.
- Most of the minerals enter the root hairs or epidermal cells of roots along with water in bulk flow, but some are taken in by diffusion, facilitated diffusion, or active transport.

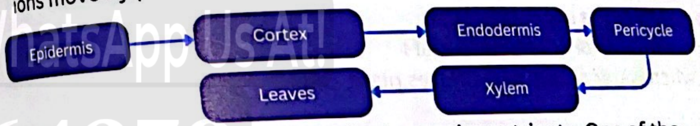
**BTB**

- The main source of carnivorous plants is autotrophic mode of nutrition like other plants.
- These plants have to capture prey and enzymes to digest the prey.
- $\Psi w = \Psi s + \Psi p$
- Water potential can also be used for movement of water from soil to roots, from leaf to air, from air to soil.
- In hypotonic solution the cell gets swell, in hypertonic solution the cell gets shrink while in isotonic solution the cells retain their shape and size.

**KPK**

- Deficiencies of the nutrients like nitrogen, phosphorus, potassium, and magnesium result in chlorosis (yellowing) and eventual necrosis (death) of older mature leaves.
- These nutrients are mobile elements that can be translocated from older to new leaves if their supply from the soil becomes limited and the young leaves become deficient in them.

- Prosopis trees of leguminoseae family have maximum depth of their roots, which is 50 metres.
- The uptake of minerals by root cells is a combination of passive uptake and active uptake, involving the use of energy in the form of ATP.
- The passive uptake involves diffusion. The minerals they also move down their concentration gradient through plasmodesmata (symplast pathway) to cells of cortex, endodermis, pericycle and then to sap in xylem cells.
- From here they are pulled up by transpiration pull to different parts of plant.
- The diffusion of ions along with water also takes place by mass flow along the apoplast pathway.
- When inorganic or organic fertilizer is applied to soil, the minerals are absorbed primarily as inorganic ions.
- The rate of absorption of each mineral by roots is essentially independent of the rates of absorption of water and of the other minerals.
- Each mineral moves into roots at a rate determined by such factors as its concentration both inside and outside the root, the ease with which it can passively penetrate cell membrane, and extent to which carrier molecules and active absorption are involved mass flow along the apoplast pathway, Ions moving in the apoplast can only reach the **endodermis**, where **casparian strips** prevent further progress
- To cross the endodermis, ions must pass by diffusion or active transport into endodermis cells, entering their cytoplasm, and possibly their vacuoles. The ions then reach the xylem cells
- Tonoplast is the membrane of vacuole.
- It has been estimated that out of total surface area provided by roots, **67%** is provided by root hairs.
- Most of ions are taken up by the roots by the process of active transport.
- Active transport is selective and is dependent on respiration. Some ions move by passive as well as by active transport.




- **Symbiotic Relationship** helps plants acquire nutrients. One of the important nutrient is nitrogen , almost always in short supply both in rock particles and in the soil water.
- Most plants have evolved beneficial relationship with other organisms that help the plants acquire these scarce nutrients. **Examples include:** Mycorrhize and nitrogen fixing bacteria in root nodules of legumes.
- The **fungal associations** with roots of higher plants, help mineral uptake by the plant.
- The fungi facilitate the uptake of phosphorus and trace metals such as zinc and copper.
- A root infected with mycorrhizal fungi can transport phosphate at a higher rate than that of an uninfected root.

**mentr**

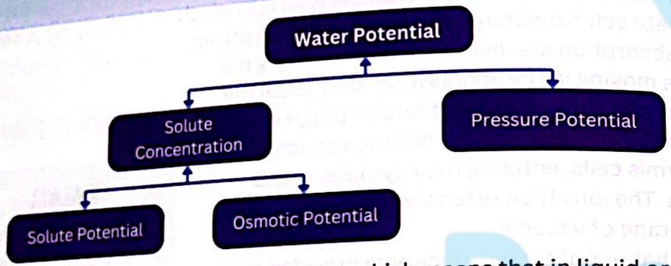
- This translocation depletes the older leaves of these essential nutrients, leading to chlorosis and necrosis.
- Vascular plants or **'tracheophytes'** have specialised tissue, termed xylem and phloem, for conducting water (plus solutes) and organic nutrients respectively.

**TID BIT**

**Blaise Pascal** was a very functional French mathematician and philosopher who contributed to many areas of mathematics.

- Mycorrhizal fungi get sugar, and shelter from the plant and in exchange increase the plant's mineral nutrient uptake efficiency.
- Mycorrhizae are present in **90% families** of flowering plants.
- Some nutrients are carried from the soil to the epidermal cells of roots through their cell membrane **by facilitated diffusion**. In this type of diffusion, carrier molecules within the cell membrane transport nutrients across the membrane.
- These **carrier molecules are proteins** - which are present within cell membrane of epidermal and other root cells.
- If water moves by osmosis into a cell the process is called endosmosis, and if the water moves out of the cell it is called exosmosis.
- The **apoplast pathway** is of **greatest importance** for both water and solutes. The **symplast pathway** is **less important**, except for salts in the region of the endodermis. Movement along the **vacuolar pathway is negligible**.
- In the cells of root the cell membrane and cytoplasm (and plasmodesmata) can be regarded as acting together as one partially permeable membrane.

## WATER POTENTIAL




**BTB**

- The pressure potential is pressure exerted by the protoplast against the cell wall of plant.
- The pressure potential maintains the shape of cell.

- Water molecules possess kinetic energy which means that in liquid or gaseous form, they move about rapidly and randomly from one place to another.
- So, greater the concentration of the water molecules in a system the greater is the total kinetic energy of water molecules. This is called water potential .
- In plant cells **two factors** determine water potential.
  1. Solute concentration (Osmotic or solute potential )
  2. Pressure generated when water enters and inflates plant cells (Pressure potential).
- **Pure water has maximum water potential which by definition is zero.**
- Water moves from a region of higher Water potential to lower Water potential.
- All solutions have lower Water potential than pure water and so have **negative value of Water potential (at atmospheric pressure and at a defined temperature).**

## OSMOTIC (SOLUTE) POTENTIAL

- The osmotic (solute) potential s is a measure of the change in water potential(s) of a system due to the presence of solute molecules.
- Solute potential is always negative.
- More solute molecules present, lower (more negative) is the Solute





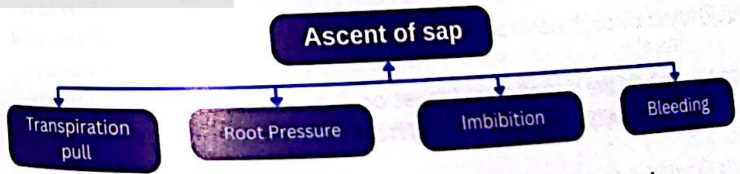
potential.

## PRESSURE POTENTIAL (P)

- If pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases.
- It is equivalent to pumping water from one place to another.
- Such a situation may arise in living systems. When water enters plant cells by osmosis pressure may be built up inside the cell making the cell turgid and increasing the pressure potential.
- Thus the total water potential is sum of Solute potential and Pressure potential.
- If we use the term water potential, the tendency for water to move between any two systems can be measured; not just from cell to cell in a plant but also from soil to root from leaf to air or from soil to air.
- The steeper the potential gradient the faster is the flow of water along it.
- kPa= 1000 Pascals which is the pressure exerted by a vertical force of one Newton on an area of 1 metre square.
- Plasmolysis can be defined as the shrinkage of protoplast due to exosmosis of water.
- When a living cell is placed in a solution having lower water potential than that of the cell, plasmolysis takes place and the cell is called plasmolysed.
- If this plasmolysed cell is placed in distilled water (which has highest water potential) the water molecules would move from distilled water through differentially permeable cell membrane into the cell, and the cell would become deplasmolysed.
- The point at which plasmolysis is just about to happen is called **incipient plasmolysis.**
- At incipient plasmolysis the protoplast has just ceased to exert any pressure against the cell wall, so the cell is flaccid.
- Full turgidity i.e. maximum pressure potential is achieved when a cell is placed in pure water or distilled water
- **The animal cells cannot withstand higher pressure potential as there is no cell wall around protoplast.**
- Thus the turgid cells burst in a solution of higher water potential.
- So the animals employ the mechanism of **osmoregulation** to maintain the amount of water and salts in their cells to constant or nearly

## ASCENT OF SAP

- Water and dissolved minerals are carried or pulled upwards towards the leaves through xylem tissue. This is called **ascent of sap.**




- Cohesion tension theory is one of the most important theories proposed **by Dixon.**
- **Transpiration** provides the necessary energy or force.

- Tension is between the molecules of water by hydrogen bonds. This xylem water tension is strong enough to pull water up to **200 metres (more than 600 feet)** in plants.
- The composition of cell wall provides necessary adhesion to water molecules that helps water creep up.
- The **cellulose component** of cell wall especially has great affinity for water. It can imbibe water
- It is essential that the xylem walls should have high tensile strength if they are not to buckle inwards. The **lignin and cellulose provides strength to cell wall of xylem vessels.**
- Large quantities of water are carried at relatively high speed, **upto** 8mh being recorded in tall trees, and commonly in other plants at 1mh"
- The total water pulled up in the leaves is transpired, except **about 1%** which is used by plant in various activities including photosynthesis.
- Transpiration pull is so strong that it also reduces the water potential of root epidermal cells. Then water in the soil moves from its higher water potential to lower water potential of epidermis of root by osmosis.

**TID BIT**

**Guttation** is the loss **of liquid water** from the leaf surface while **transpiration** is the loss of **gaseous water (vapours)**.

## ROOT PRESSURE (POSITIVE PRESSURE)

- Second force involved in the movement of water and dissolved minerals up in the xylem tissue is the root pressure.
- Root pressure is created by the active secretion of salts and other solutes from the other cells into the xylem sap.
- This lowers the water potential of xylem sap. Water enters the xylem cells by osmosis, thus increasing the level of sap in the xylem cells.
- Water entering the xylem cells, may take apoplast, symplast or vacuolar pathway increasing the hydrostatic pressure in cells, this pushes the water upwards.
- As a result of root pressure the sap in the xylem does not rise to enough height in most plants.
- The root pressure is also least effective during the day, when transpiration pull is the active force involved in pulling the sap in xylem cells upwards.
- It has been estimated that a positive hydrostatic pressure of around **100 to 200 KPa (exceptionally 800 KPa) is generated by root pressure.**
- The pressure mentioned above is not enough to push water upwards to required height in most plants. But it is no doubt a contributing factor in plants which transpire slowly, and are smaller in size.
- Closely associated with root pressure is a phenomenon called **guttation or exudation.**
- Guttation is loss of liquid water through water secreting glands or **hydathodes.**
- The dew drops that can be seen on the tips of grass leaves or strawberry leaves are actually guttation droplets exuded from hydathodes.
- Guttation or exudation is more notable when transpiration is suppressed, and the relative humidity is high as at night.
- The guttation is in fact due to positive pressure the root pressure,



developed in xylem tissue of roots.

- Guttation by strawberry leaves.

## IMBIBITION

- Another important force in the ascent of sap is imbibition.
- **Sacks** in 1874 suggested that the water molecules move along the cell walls of xylem vessels due to imbibition.
- The cell wall components especially cellulose, pectin and lignin can take up water and as a result increase in volume, but the components do not dissolve in water, this is called imbibition
- The amount of attraction and increase of dry cell walls of plant cells, and of protoplasm for water is often very great and considerable imbibition forces may be developed in plant body.
- The root cell walls imbibe water from the soil, and this water moves by apoplast pathway already discussed.
- Imbibition is a **reversible process** and when water is lost the original volume of cell wall and of protoplasm is restored.
- The uptake of water by imbibition is especially important in germinating seeds.
- **The volume of dry seed may increase up to 200 times by** imbibition, as a result, the seed coat ruptures and makes the germination of seed effective.

## BLEEDING

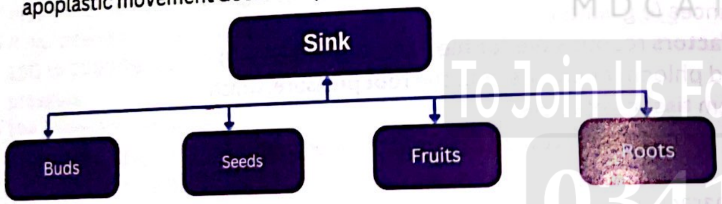
- Sometimes it so happens that certain plants, when cut, pruned, tapped or otherwise wounded, show a flow of sap from the cut ends or surfaces quite often with a considerable force.
- This phenomenon is commonly called bleeding. It is often seen in many land plants in the spring, particularly grape wine, some palms, sugar maple etc.
- Although the flow of sap is ordinarily slow, a considerable quantity of the sap within a period of **24 hours** comes out of the plant.
- In some palms when tapped, there may be a flow of sap to the extent of **10-15 litres per day.**
- The sap in such plants contains sugars and water in addition to organic and inorganic substances (e.g. salts).
- There are **two main factors** responsible for bleeding, the **hydrostatic pressure** in xylem and phloem elements, and the **root pressure**, which is exerted by the xylem tissues of roots.
- Only sieve tube cells are directly involved in transport of organic solutes.
- Sieve elements are characterised by 'sieve areas' portions of the cell wall where pores interconnect the conducting cells
- Some of the sieve areas of sieve tube members are generally formed in end walls of sieve tube members where the individual cells are joined together to form a longitudinal series called a sieve tube.
- Sieve plate pores of sieve tubes are essentially open channels, that allow transport between cells
- Each sieve tube member is associated with a companion cell (b) Sieve tube member showing the pores in its end walls.
- Each sieve tube member is associated with one or more companion

cell (b) Sieve tube member showing the pores in its end walls.

- Each sieve tube member is associated with one or more companion cells. Sieve tubes and companion cells are in communication with each other by plasmodesmata
- Companion cells supply ATP and proteins to sieve tubes.
- **The areas of sources** include any exporting organ typically a mature leaf, or storage organ, that is capable of

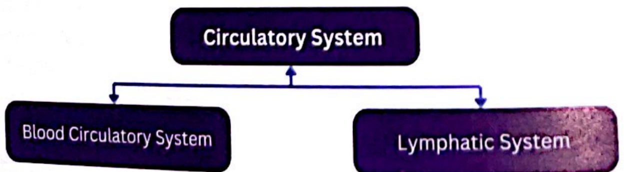
i) Storing photosynthate in excess of its own needs **ii)** Storage organ during the exporting phase of development.

- In biennials e.g. root of **beet is a sink in first growing season, but becomes source in the next growing season**, when sugars are utilized in growth of new shoots.
- The composition of materials flowing in phloem has been studied by **using aphids** - the insects which are **iii)** Sinks are the areas of active metabolism or storage for example roots, tubers, developing fruits, immature leaves, and even the growing tips of stem and root.
- These insects insert their stylets into stem or leaf and extend them to puncture a sieve tube. The pressure in the sieve tube cell forces sap through aphid's digestive tract and out its posterior end as droplets called **"honey dew"**.
- The composition of honey dew have revealed that it contains **10-25% dry matter 90% or more of which is sucrose**. Nitrogenous compounds are about 1%.
- Pressure Flow Theory, is the most acceptable theory for the transport in the phloem of angiosperms
- **Pressure flow theory:** A hypothesis was first proposed by Ernst Munch in 1930. It states that the flow of solution in the sieve elements is driven by an osmotically generated pressure gradient between source and sink.
- Now this hypothesis has been given status of a theory.
- This sucrose is actively transported through the bundle sheath cells to the companion cell of the smallest vein in leaf, a short distance transport **(involving 2-3 cells)**.
- The pathway taken by sucrose is symplast in most cases; but in some, apoplastic movement does take place.




## TRANSPORT IN MAN

In humans, the circulatory system is divided into **BLOOD CIRCULATORY SYSTEM** and the **LYMPHATIC SYSTEM**, described latter in this chapter

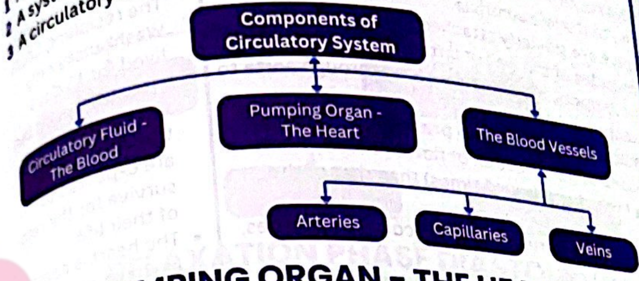



**TID BIT**
Cardio-logy from Greek **Kardia** 'HEART' AND **Logia** 'STUDY' is branch of medicine dealing with disorders of heart as well as parts of circulatory system.



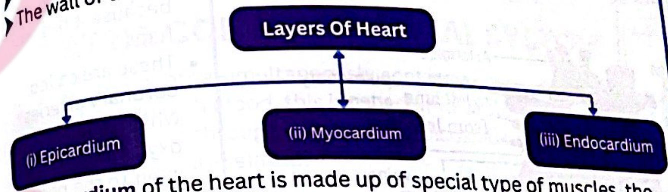


The circulatory system of humans have the same 3 basic components.
1. A muscular pumping organ **(Heart)**
2. A system of interconnecting tubes **(Blood vessels)**
3. A circulatory fluid **(The Blood)**




## PUMPING ORGAN – THE HEART

- The heart is enclosed in a double membranous sac - the pericardial cavity, which contains the pericardial fluid.
- **Pericardium** protects the heart, prevents it from over extension.
- The heart of humans is located in the chest cavity.
- The wall of the heart is composed of three layers:

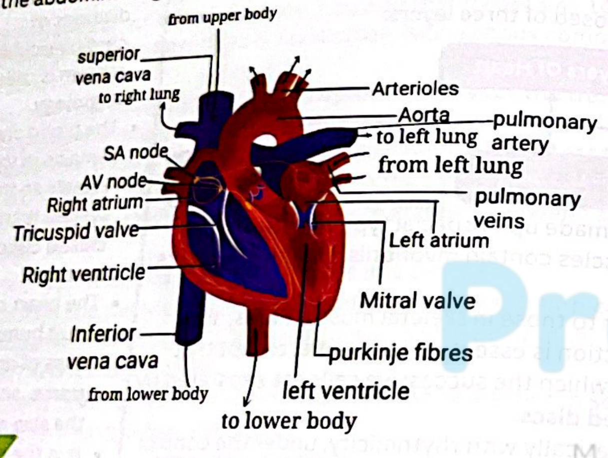



- **Myocardium** of the heart is made up of special type of muscles, the **cardiac muscles**. These muscles contain myofibrils, and myofilaments of myosin and actin.
- Their arrangement is similar to those in skeletal muscle fibres, and their mechanism of contraction is essentially the same, except that they are **branched cells**, in which the successive cells are separated by junctions called **intercalated discs**.
- The heart contracts automatically with rhythmicity, under the control of **the autonomic nervous system of the body**.
- There are **four chambers** of the heart: **two upper** thin-walled atria, and **two lower** thick walled ventricles.
- Human heart functions as a **double pump**, and is responsible for pulmonary and systemic circulation.
- Complete separation of deoxygenated blood (Right side) and oxygenated blood (left side), in the heart, is maintained.
- The right atrium receives deoxygenated blood via venae cavae from the body.
- The blood is passed on to right ventricle through **tricuspid valve** (called so because it has 3 flaps).
- These flaps are attached with fibrous cords called **chordeae tendinae**, to the papillary muscles which are extensions of the wall of the right ventricle.
- When right ventricle contracts, the blood is passed to pulmonary trunk,which carries blood via left and right pulmonary arteries, to the

**BTB**
- Tiny animals have small size and large surface area so this process of diffusion is sufficient to meet their required transport of substances.
- The larger and active animals like human cannot rely on diffusion alone.
- Therefore these animals must need an efficient transport system.
- The study of diseases of cardiovascular system is called **angiology**.
- The blood always remains in the vessels so the system is known as **closed circulatory system**.
- The heart of an adult human has a mass of around **300 grams**, and is about the **size of our fist**.
- It is the most powerful organ in the circulatory system.
- The heart lies in the thoracic cavity between the lungs, slightly towards left, enclosed within the rib cage, with the sternum in front and vertebral column behind.
- It is surrounded by a double layered pericardium.

lungs.

- At the base of the pulmonary trunk, semilunar valves are present.
- After oxygenation in lungs the blood is brought by pulmonary veins to the left atrium, which passes this blood via **bicuspid valve** (called so because it has two flaps) to the left ventricle.
- The flaps of bicuspid valve are similarly attached through chordae tendinae, to **papillary muscles** of the wall of left ventricle.
- When the left ventricle contracts, it pushes the blood through **aorta** to all parts of the body (except lungs).
- At the base of aorta **semilunar valves are also present.**
- The valves of the heart control the direction of flow of blood.
- The wall of **left ventricle is thicker (about 3 times)** than that of the right ventricle.
- At the base of aorta, first pair of arteries, called the coronary arteries, arise, and supply blood to the heart.
- The aorta forms an arch, and before descending down gives three branches supplying blood to head, arms and shoulders.
- The aorta descends down in the chest cavity.
- It gives many small branches to the chest wall and then passes down to the abdominal region.




**PTB**

- Aorta gives branches, which supply blood to different parts of alimentary canal, kidneys and the lower abdomen.
- The aorta Bifurcates into iliac arteries, each of which leads to supply blood to each legs.
- The blood from the upper part of the body is collected by different veins, which join to form superior vena cava; which passes blood to the right atrium.
- Two **iliac veins** are formed by veins which collect blood from legs, and unite to from inferior vena cava.
- It receives renal vein from each kidney; and hepatic vein from the liver, before it enters the right atrium.
- The **liver receives hepatic portal vein** which is formed by many veins collecting deoxygenated blood with absorbed food from different parts of alimentary canal.

- **De Christen Barnard** carried out the first heart transplant in 1967. The recipient, Louis Washkansky only lived for 18 days after transplant but now most heart transplant patients are expected to survive for the rest of their life.
- The heart is conical in shape and dark red in colour.
- The valve on the left is often known as mitral valve, or alternatively the bicuspid valve because it has two flaps.
- These are called coronary arteries which deliver oxygenated blood itself to the heart walls
- **Heart block** is a disease or inherited condition that causes a fault within the natural pace maker of the heart, due to some kind of obstruction or block in the electrical conduction system of heart.
- Adult human heart beats around 72 **times per minute.**
- The volume of blood out the leaving the the left ventricle is known the **stroke volume**
- **Cardiac output** is the volume of blood





## THE CARDIAC CYCLE

Phases Of Cardiac Cycle
- Relaxation Of Diastole
- Contraction Of Systole
  - Atrial Systole
  - Ventricular Systole

## RELAXATION PHASE DIASTOLE

- The deoxygenated blood enters right atrium through vena cava, and oxygenated blood enters left atrium through pulmonary veins.
- The walls of the atria and that of ventricles are relaxed.
- As the atria are filled with blood, they become distended and have more pressure than the ventricles.
- This relaxed period of heart chambers is called diastole.

## ATRIA CONTRACT ATRIAL SYSTOLE

- The muscles of atria simultaneously contract, when the atria are filled and distended with blood, this is called atrial systole.
- The blood passes through tricuspid and bicuspid valves, into the two ventricles which are relaxed.

## VENTRICLES CONTRACT – VENTRICULAR SYSTOLE

- When the ventricles receive blood from atria, both ventricles contract simultaneously and the blood is pumped to pulmonary arteries and aorta.
- The tricuspid and bicuspid valves close, and 'lubb' sound is made.
- Ventricular systole ends, and ventricles relax at the same time semilunar valves at the base of pulmonary artery and aorta close simultaneously, and 'dubb' sound is made.
- Lubb, dub can be heard with the help of a stethoscope.
- One complete heartbeat consists of one systole and one diastole, and lasts for about 0.8 seconds.

**PTB**

- In one's life, heart contracts about **2.5 billion times,** without stopping

## MECHANISM OF HEART EXCITATION AND CONTRACTION

- The heart beat cycle described above starts when the sino-atrial node (Pace maker) at the **upper end of right atrium** sends out elec trical

leaving the left ventricle per minute.

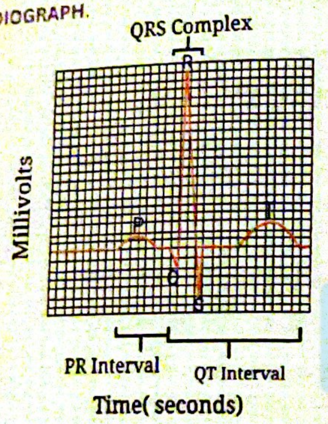
- cardiac output = stroke volume x heart rate
- The sinoatrial node was first discovered by a young medical student Martin Flack in the heart of mole, a small mammal.
- The **electrocardiogram( ECG)** also known as EKG.
- It is a non-invasive device that measures and records the electric activity of the heart over a period of time using electrodes placed on the skin.
- These electrodes detect the tiny electrical changes on the skin that arise from the heart muscles that is electrophysiologica l pattern of depolarization and repolarization during each heartbeat
- The overall goal of performing electrocardiograph y is to obtain information about the function of heart e.g., **suspected myocardial infarction, suspected embolism, increase in size heart,** to

impulses to the atrial muscles, and causing both atria to contract

- The sino-atrial node consists of a small number of diffusely oriented cardiac fibres, possessing few myofibrils; and few nerve endings from the autonomic nervous system.
- Sinoatrial node (SA node) impulses from the node travel to the musculature of the atrium and to a atrioventricular node.
- From it an atrioventricular bundle of muscle fibres propagates the regulatory impulses via excitable fibres in interventricular septum, to the the myocardium of the ventricles.
- There is a delay of approximately **0.15 second** in conductance from the S-A node to A-V node, permitting atrial systole to be completed before ventricular systole begins

## ELECTROCARDIOGRAM

- The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an electrocardiogram (ECG).
- The instrument used to detect these electrical changes is called ELECTROCARDIOGRAPH.




- **TP Interval** (Ventricular diastole)
- **P Wave** (Atrial Systole)
- **QR Interval** (End of Ventricular Diastole)
- **RS Interval** (Ventricular Systole)
- **ST Segment** (Ventricular Systole)
- **T Wave** ( Ventricular Diastole)
- As the cardiac impulse passes through the heart, electrical currents spread into the tissues surrounding the heart, and a small proportion of these spread all the way on the surface .
- A normal electrocardiogram (ECG) indicates that the heart is functioning properly.
- The **P wave** occurs just prior to atrial contraction; the **QRS** wave occurs just prior to ventricular contraction and the **T wave** occurs when the ventricles are recovering from contraction body.
- If electrodes are placed on the skin on opposite sides of the heart, electrical potentials generated by these currents can be recorded.
- This recording is known as electro cardiogram which is taken by electrocardiograph (E.C.G.) machine.

access the ... of electro... abnormal... **Sinus bradycardia** is a sinus rhythm with a rate ... lower than ... In humans bradycardia is generally defined to be a rate of under 60 beat per minute while **sinus tachycardia** is a sinus rhythm with a elevated rate of impulses usually greater than 100 **per minute**.

**KPK**

- Vena cava is the largest vein.
- Normal rate of heartbeat in a healthy human being is **72 beats** per minute.
- This rate decreases when a person is resting or sleeping and increases to **120 per minutes** duringmuscular exercise running ,swimming etc. and with some medicines like caffeine.
- Every time heart pours about 85 ml of blood into aorta with a great pressure.
- Blood travels, in all different types of vessels, at different speeds.
- Speed is fastest in arteries, slower in





- It helps to diagnose the abnormalities in the rhythmicity and conduction system of the heart which may be corrected by the use of artificial pacemaker.

**PTB**

## ARTIFICIAL PACEMAKER

- Artificial pace maker Pacemaker is responsible for initiating the impulses which trigger the heart beat rate.
- If there is some block in the flow of the electrical impulses, or if the impulses initiated by S.A. node are weak; It may lead to death of the individual.
- So an artificial pacemaker, which is battery operated producing electrical stimulus is used.
- For example if A-V pathway is blocked, the electrodes of artificial pacemaker are attached to the ventricle. Then this pacemaker provides continued rhythmic impulses that take over the control of ventricles.

## BLUE BABIES

- Failure of **interatrial foramen** (an opening in the inter-atrial septum) to close or of ductus arteriosus to fully constrict results in **cyanosis (blueness of skin)** of new born.
- This is due to mixing of blood between two atria and the mixed blood is supplied to the body of newborn babies resulting in blueness of skin, thus the name blue babies.

**FTB**

- All organisms must exchange materials with their environment and distribute materials within their bodies.
- Most animals have a system of internal transport.
- circulatory system that transports oxygen and carbon. dioxide, distributes nutrients to the body cells and conveys the waste products of metabolism to specific site for disposal.
- The circulatory system of man is divided into cardiovascular system and lymphatic system.
- The cardiovascular system consists of a strong muscular heart, three kinds of blood vessels: arteries, capillaries, veins and blood
- The human heart is a hollow, fibro muscular organ.
- The Greek name for the heart is cardia from which we have the adjective cardiae.
- The Latin name for the heart is coronary from which we have adjective coronary.
- The adult heart has the shape of a cone. The blunt, rounded point of the cone is the apex and the larger flat part at the opposite end of the cone is the base.
- The heart is located in the thoracic cavity between the lungs called mediastinum.
- The heart lies deep and obliquely in the mediastinum and slightly to the left of the sternum.

arterioles and slowest in capillaries.

- From here it starts getting collected in venules.
- Its speed starts increasing in venules and faster again in veins.
- The continuous working of heart is due to certain specialized structures like SA node (also called pacemaker), AV node and some specific type of fibers called purkinjifibers.
- The pacemaker or SA node (sino-atrial node) is the impulse-generating (pacemaker) tissue located in the **upper dorsal wall of** the right atrium of the heart, near the entrance of the superior vena cava
- SA node initiates the electrical impulses for heart beat and keeps the heart in motion.
- AV node is an electrical relay station between the atria and the ventricles.
- Electrical signals from the atria must pass through the AV node to reach the ventricles.
- This node slows down the speed of the electrical signals to ...

- The base of heart deep to the sternum, extends to the second intercostals space and the apex of the heart is in the **fifth intercostals** space, approximately **9 cm** to the left of the midline.
- The pericardium is a closed sac that surrounds heart. It consists of two parts; the **outer part and inner part. The outer part** consists of inelastic white fibrous tissue. **The inner part** is made up of two membranes.
- The inner membrane is attached to the heart and the outer one is attached to the fibrous tissue.
- Pericardial fluid is secreted between them and reduces the friction between the heart wall and surrounding tissues when the heart is beating.
- The **inelastic nature** of the **pericardium** as whole prevents the heart from being overstretched or overfilled with blood.
- **Pericarditis** is an inflammation of the serous pericardium.
- It can be extremely painful, with sensations of pain referred to the back and the chest which can be confused with the pain of myocardial infarction (heart attack
- On the surface of the heart they are separated from each other by an atrioventricular groove or **sulcus (meaning ditch)**.
- The atria are separated from each other by an interatrial groove.
- The ventricles are separated from each other by an interventricular groove.
- In normal intact heart the **sulci** are covered by fat and only after this fat is removed the actual sulci can be seen.
- The heart wall is composed of the **three layers of tissue.** The epicardium, the myocardium, and the endocardium.
- **The epicardium** is a thin serous membrane comprising of the smooth outer surface of the heart.
- The thick middle layer of the heart, the **myocardium**, is composed of cardiac muscle cells and is responsible for the ability of the heart to contract.
- The smooth inner surface of the heart chambers is the endocardium, which consists of simple **squamous epithelium** over a layer of connective tissue.
- The smooth inner surface allows blood to move easily through the heart.
- The **heart valves** are formed by a **fold of the endocardium**, making a double layer of endocardium with connective tissue in between.
- The right ventricle has thinner walls than the left ventricle in a ratio **of 1:3. it pumps** blood to the lungs, which are at a short distance from the heart.
- The atria have comparatively thin walls as they only have to force blood into the ventricles and this does not require much power. On the other hand, the ventricles have to force blood out of the heart hence they have relatively thick walls, especially the left ventricle which has to pump blood round the whole body.
- The superior vena cava and the inferior vena cava, both carrying deoxygenated blood, enter the right atrium.
- The right atrium receives **three veins** the superior vena cava, the inferior vena cava, and the coronary sinus.

contraction of ventricles until the atria are not fully contracted.

- Purkinji Fibers were discovered in [illegible] by Jan Evangelista Purkinji.
- **Purkinji fibers** are the extension of the autonomic nervous system.
- They are found in **the inner wall** of the ventricle just beneath the **endocardium.**
- In ECG, when the overall electrical current of the heart goes towards a particular lead, it registers a positive deflection.
- Those that go away from the lead register a negative deflection.
- Those which are at 90 degrees or perpendicular to the vector of the lead registers 0, is seen as an isoelectric line.
- **During Ventricular Diastole** both Atria and ventricles are relaxed; blood is flowing into the atria from the veins
- **SA node** is also called **heart of heart**.
- **AV node** is called **amplifier of heart**





- The left atrium receives the **four pulmonary veins.**
- The two atria are separated from each other by the interatrial septum.
- The atria open into the ventricles through atrioventricular canals.
- The right ventricle opens into the pulmonary trunk, and the left ventricle opens into the aorta.
- The two ventricles are separated from each other by the interventricular septum.
- An atrioventricular valve is on each atrioventricular canal and is composed of cusps, or flaps.
- These valves allow blood to flow from the atria into the ventricles, but prevent blood from flowing back into the atria.
- The atrioventricular valve between the left atrium and left ventricle has two cusps and is therefore called the bicuspid or **mitral (meaning, resembling a bishop's miter, a two-pointed hat)** valve.
- Each ventricle contains cone-shaped muscular pillars called papillary (meaning, pimple-shaped) muscles.
- These muscles are attached by thin, strong connective tissue strings called **chordae tendineae** (meaning, heart strings) to the cusps of the atrioventricular valves.
- The papillary muscles contract when the ventricles contract and prevent the valves from opening into the atria by pulling on the chordae tendineae attached to the valve cusps.
- Semilunar Valves The aorta and pulmonary trunk possess aortic and pulmonary semilunar (meaning halfmoon-shaped) valves.
- Each valve consists of **three pocketlike** semilunar cusps, the free inner borders of which meet in the centre of the artery to block blood flow.
- The superior vena cava and the inferior vena cava, both carrying deoxygenated blood, enter the right atrium.
- The right atrium sends blood through an atrioventricular valve (the tricuspid valve) to the right ventricle
- The right ventricle sends blood through the pulmonary semilunar valve into the pulmonary trunk and the two pulmonary arteries to the lungs.
- Four pulmonary veins, carrying oxygenated blood from the lungs, enter the left atrium.
- The left atrium sends blood through an atrioventricular valve (the bicuspid valve) to the left ventricle.
- The left ventricle sends blood through the aortic semilunar valve into the aorta to the body proper.
- The heart is a double pump because the right ventricle of the heart sends blood through the lungs, and the left ventricle sends blood throughout the body

## HEART BEAT AND ITS CONTROL

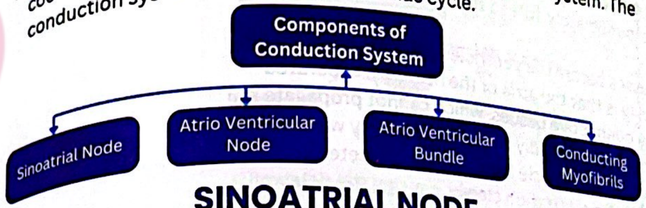
- The heart is the hub of the circulatory system.
- In a continuous, rhythmic cycle it passively fills with blood from the large veins and then actively contracts, propelling the blood throughout the body.
- Its alternating relaxations and contractions make up the cardiac cycle
- The term systole means to contract and diastole means to dilate.
- Atrial systole is contraction of the atrial myocardium and atrial

diastole is relaxation of the atrial myocardium.

- Similarly ventricular systole is contraction of the ventricular myocardium and ventricular diastole is the relaxation of the ventricular myocardium.
- When the word "systole" and "diastole" are used without reference to specific chambers, they mean ventricular systole or diastole.
- ***Atrial Diastole:*** *Blood enter the right atrium from the body through the vena cavae.*
- *At first the bicuspid and tricuspid valves are closed, but as the atria fill with blood, pressure in them rises.*
- *Eventually it becomes greater than that in the relaxed ventricles and the valves are pushed open.*
- ***Atrial Systole:*** *The two atria contract simultaneously and blood is pushed through the atrio-ventricular valve into the still relaxed ventricles.*
- *At this phase semilunar valve is closed, tricuspid and bicuspid valves are open.*
- ***Ventricular Systole:*** Almost immediately the ventricle contract. When this occurs the pressure in the ventricles rises and closes the atrioventricular valves, preventing blood from returning to the atria. This pressure forces, open semilunar valves of the aorta and the pulmonary artery and blood enters these vessels. In this phase the tricuspid and bicuspid valves are closed.
- ***Ventricular Diastole:*** The high pressure developed in the aorta and pulmonary artery tends to force some blood back towards the ventricles and close the semilunar valves of the aorta and pulmonary artery.
- Hence back flow in the heart is prevented. In this phase bicuspid valve and tricuspid valve are open, aortic semilunar valve, and pulmonary semilunar are closed.
- The normal cardiac cycle of **0.7 to 0.8 second** depending on the capability of cardiac muscle to contract.
- The heart muscle rests **0.1 to 0.3 second** between the beats.
- When a stethoscope is used to listen to the heart sounds, distinct sounds normally are heard.
- The first heart sound is a **low-pitched sound,** often described as a **"lubb" (lub) sound**. It is caused by vibration of the atrioventricular valves which close near the beginning of ventricular systole.
- The second heart sound is a higher pitched sound often described as a **"dupp" (dub) sound.**
- It results from closure of the aortic and pulmonary valves, near the end of systole

## ATRIA CONTRACT ATRIAL SYSTOLE

- Most muscles contract as a result of impulses reaching them from nerves. This is not, however true of the heart, which will continue beating.
  1. Action potentials originate in the sinoatrial (SA) node and travel across the wall of the atrium from the SA node to the atrio-ventricular (AV) node.
  2. Action potentials pass through the AV node and along the atrioventricular (AV) bundle, which extends from the AV node, through the fibrous skeleton, into the Bundle of Hiss.
  3. The AV bundle divides into right and left bundle branches, and action potentials descend to the apex of each ventricle along the bundle branches.
  4. Action potentials are carried by the Purkinje fibres from the bundle branches to the ventricular walls.
- The heart will go on beating after it has been cut right out of the body.
- Cardiac muscles are therefore **myogenic (myo: muscle, genic: giving rise to) i.e.** its rhythmic contraction arise from within the muscle itself
- Cardiac muscle has an intrinsic rhythmicity that allows the heartbeat to originate in and be conducted through the heart without extrinsicstimulation.
- Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the conduction system. The conduction system constitutes the cardiac cycle.




## SINOATRIAL NODE

In short it is called SA node. It consists of specialized plexus of cardiac muscles embedded in the upper wall of the right atrium. It is close to where vena cavae enter the atrium.

- The SA node has been developed from the sinus venosus and has become a part of the atrium, so it is called sinoatrial node.

## ATRIOVENTRICULAR NODE

There is another specialized group of cardiac muscle fibres called atrioventricular node. In short it is called AV node. It is present near the junction of right atrium and right ventricle.

## ATRIOVENTRICULAR BUNDLE

AV node is connected to a strand of specialized muscles (in the ventricular septum) known as AV bundle or **bundle of His** (pronounced as "hiss").

- This bundle passes through a small opening in the fibrous skeleton to reach the interventricular septum, where it divides to form right and left bundle branches, which extend beneath the endocardium on either side of the interventricular septum to the apices of the right and left ventricles respectively.
- The inferior, terminal branches of the bundle branches are called **Purkinje fibres**, which are large-diameter cardiac muscle fibres.
- They have fewer myofibrils than most cardiac muscle cells and do not contract forcefully.
- Intercalated disks are well developed between the Purkinje fibres and contain numerous gap junctions.
- As a result of these structural modifications, action potentials travel along the Purkinje fibres much more rapidly than through other

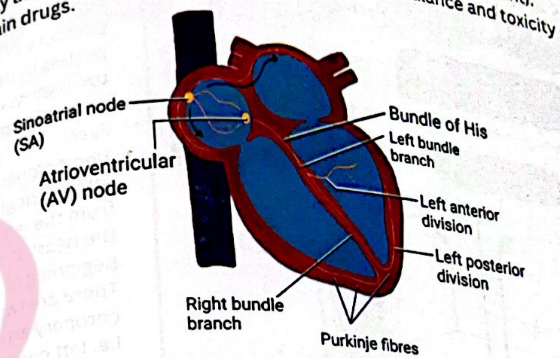
cardiac muscle tissue.

- Cardiac muscle cells have the capacity to generate spontaneous action potentials, but cells of the SA node do so at a greater frequency.
- As a result, the SA node is called the **pacemaker** of the heart.
- When the heart beats under resting conditions, approximately **0.04 second** is required for action potentials to travel from the SA node to the AV node.
- Within the AV node action potentials are propagated slowly compared with the remainder of the conducting system.
- As a consequence, there is a delay of **0.11 second** from the time action potentials reach the AV node until they pass to the AV bundle.
- The total delay of 0.15 second allows completion of the atrial contraction before ventricular contraction begins.
- Reason for the slight delay between the atrial and ventricular contraction does not immediately spread to the ventricles from SA node.
- Almost **0.1 second** passes before the ventricles start to contract.
- The reason for the delay is that the atria of the heart are separated from the ventricles by connective tissues, which cannot propagate a wave of electrical excitation. Secondly the cells that carry wave of impulse from the atria to the ventricle have smaller diameter.
- Thus they propagate the **depolarization slowly,** causing the delay of contraction of ventricles.
- This delay permits the atria to finish the emptying the contents into the corresponding ventricles before the ventricles start to contract.
- A **cardiac arrhythmia** is a disturbance in electrical rhythm of heart. It may be **bradycardia** (heart beat less than 40 beats per minute) or **tachycardia** (heart beat more than 100 beats per minute).
- Pacemaker supplies electrical initiation to myocardial contraction. The pacemaker is put surgically under the skin where it may be programmed. It generates electrical rhythm at a set rate, so in this way arrhythmia are controlled.
- The electrical impulses that pass through the conduction system of the heart during the cardiac cycle can be recorded as an electrocardiogram (ECG).
- The electrical changes result from depolarization and repolarization of cardiac muscle fibres and can be detected on the surface of the skin skin using an instrument called the electrocardiograph.
- Depolarization of the atrial fibres of the SA node produces the P wave. The ventricles of the heart are in diastole during the expression of the P wave.
- On the ECG recording, the P-R interval is the period of time from the start of the P wave to the beginning of the QRS complex.
- This interval indicates the amount of time required for the SA depolarization to reach the ventricles.
- The QRS complex begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the depolarization of the ventricles. During this interval, the ventricles are in systole and blood is being ejected from the heart.



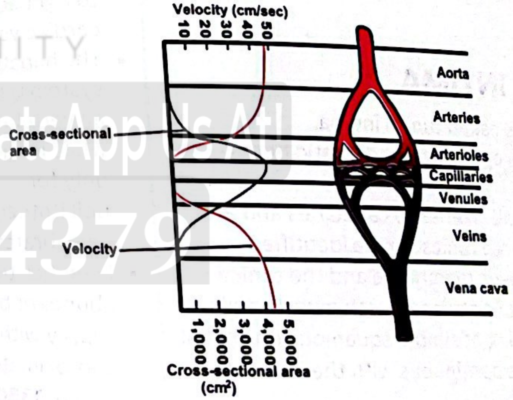


- The time duration known as the S-T segment represents the period between the completion of ventricular depolarization and initiation of repolarization. The T wave is produced by ventricular repolarization.
- ECG is used to detect cardiac arrhythmias and conduction defects.
- It is used to diagnose and localize myocardial hypertrophy (increase in size of heart), **Ischemia** or **Infarction** (decrease in oxygen content).
- It may also give information about electrolyte imbalance and toxicity of certain drugs.




## BLOOD VESSELS

- The heart provides the major force that causes blood to circulate, but the blood vessels carry blood to all tissues of the body and back to the heart.
- In addition, the blood vessels take part in the regulation of blood pressure and help to direct blood flow to tissues that are most active.
- The circulatory system has **three types** of blood vessels, the **arteries (and arterioles)**, which carry blood away from the heart, **the veins**, which return blood to the heart, and **capillaries**, which permit exchange of materials with the tissues.



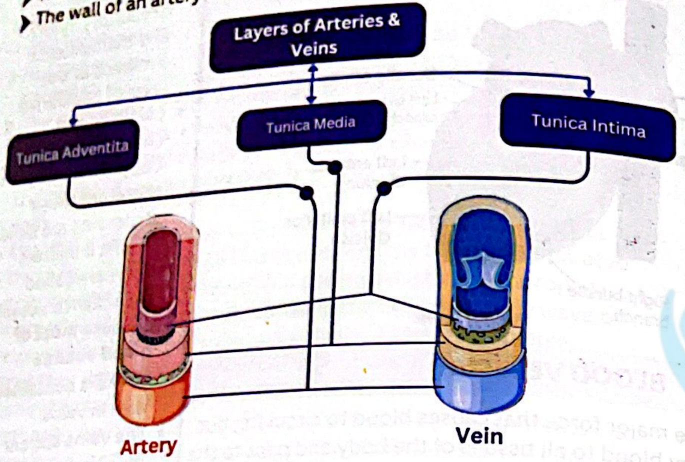

## ARTERIES

- Arteries carry blood away from the heart.
- All arteries carry oxygenated blood except the **pulmonary arteries**, which carry deoxygenated blood.

**BTS**

- Greek arteria meaning **wind pipe**
- The intimate relationship between the circulatory system and the tissues is achieved at the level of capillaries.
- Cartilage and cornea lack Cappillaries and therefore these structures are slow to heal if injured.
- Veins are called capacitance vessels because **most of blood volume (60%)** is contained with in veins.
- The veins appear blue because the subcutaneous fat absorb low frequency of light and reflect blue light.
- **Cardiac veins:** The vessels that remove deoxygenated blood from the heart muscles
- Most veins carry deoxygenated blood except the pulmonary vein and **umbilical veins.**
- Veins mostly contain valves which prevent back-ward flow of blood
- These valves are present in larger veins having diameter greater than 2mm.

- Arteries are pink in colour and are situated within the muscles.
- Arteries vary in size. Aorta is approximately 23 mm and arterioles are about 0.2 mm in diameter.
- Arteries have thick muscular walls.
- These branch into arterioles and capillaries.
- Arteries are distributing vessel and carry blood under pressure.
- The lumens of arteries have no valves.
- The wall of an artery consists of three coats or tunics:




## ADVENTITIA TUNICA

- The outermost layer is called tunica adventitia or tunica externa.
- It is composed of white fibrous connective tissue.

## TUNICA MEDIA

- The middle layer is called tunica media, and has variable amount of elastic fibres.
- It is many layered in thickness.

## TUNICA INTIMA

- The innermost layer of the artery is called tunica intima.
- It is composed of simple squamous epithelium and elastic fibres composed of elastin.
- Arterioles transport blood from small arteries to capillaries and are the smallest arteries in which the three tunics can be identified.
- The tunica intima has no internal elastic membrane and the tunica media consists of one or two layers of circular smooth muscle cells.
- All blood vessels have an internal lining of simple squamous epithelial cells called the endothelium, which is continuous with the endocardium of the heart.
- The capillary wall consists primarily of endothelial cells, which rest on a basement membrane.
- Outside the basement membrane a delicate layer of loose connective tissue called the adventitia that merge with the connective tissue surrounding the capillary.

- A pre-capillary sphincter is a band of smooth muscle that adjust blood flow into capillaries.
- Portal hypertension is a condition in which the blood pressure of the portals system is too high which may cause cirrhosis of liver.
- Two coronary arteries originate from the left side of the heart at the beginning of aorta. There are two main coronary arteries i.e. left coronary which supplies oxygenated blood to left side of heart and right coronary artery which supplies oxygenated blood to the right side of heart.
- The deoxygenated blood is taken back to right atrium by cardiac veins.
- The hepatic portal system is present in all vertebrates while renal portal only for poikitotherms vertebrates.
- Liver has the most abundant blood supply with approximate blood flow of **1350ml/min**
- kidneys and brains are the second and the third most supplied organs with **1100 and 700**





## CAPILLARY NETWORK

- Arterioles supply blood to each capillary network blood then flows through the capillary network and into the venules.
- Blood flows from arterioles through **metarterioles**. From a metarteriole blood flows into a **thoroughfare channel**.

Arteries → Arterioles → Meta Arterioles → Capillaries → Veins

- Several capillaries branch from the thoroughfare channels.
- Flow in these capillaries is regulated by smooth muscle cells called **precapillary sphincter**, which are located at the origin of the branches.
- This sphincter can open and close the entrance to the capillary.

## VEINS

- The blood vessels that bring blood back to the heart are called veins.
- Veins are relatively not deep in the muscles.
- Veins can be seen as blue vessels under the skin.
- A vein also consists of tunica adventitia, tunica media and tunica intima.
- Tunica adventia is composed of collagenous connective tissue.
- **Tunica media is a composed of a thin layer of circularly arranged smooth muscle cells, collagen fibres and a few sparsely distributed elastic fibres.**
- Tunica intima is a thin layer and consists of endothelial cells, a relatively thin layer of collagenous connective tissue and a few scattered elastic fibres.
- Venules with a diameter of **40 to50 μm** are tubes composed of endothelium resting on a delicate basement membrane.

## ROLE OF ARTERIOLES IN VASOCONSTRICTION AND VASODILATION

- The amount of blood flowing through a blood vessel can be regulated by contraction or relaxation of **smooth muscle in the tunica media.**
- A decrease in blood flow results from **vasoconstriction**, a decrease in blood vessels diameter caused by smooth muscle contraction
- Whereas an increase in blood flow is produced by **vasodilation** an increase in blood vessel diameter because of smooth muscle relaxation.

## VASOCONSTRICTION AGENTS

- Blood circulation is also controlled by hormones (vasoconstriction agents) acting on arterioles.
- **Norepinephrin** is an especially powerful vasoconstriction hormone, and epinephrine is less.

## VASODILATOR AGENTS

- Several substance called **kinins** (vasodilator agents) can cause powerful vasodilation are formed in the blood and tissue fluids of some organs. **e.g histamine.**

mL/min respectively

**KPK**

- A network of small arteries called the **vasa vasorum (means vessels of vessels).**
- Arterioles are the smallest arteries with a diameter ranging from **3 mm to 10 micrometers.**
- Larger arterioles have all three layers but smaller arterioles have only two; a thin layer of endothelium surrounded by a single layer of smooth
- Colour of the arteries appears to be red due to the bright red **oxygenated blood** flowing through them. Whereas due to **deoxygenated blood veins appear to be bluish**
- The largest artery of the body is aorta, which arises from left ventricle.
- In circulatory system, the smallest blood vessels are capillaries. Their **diameter is 8-10 micrometer.**
- When capillary pressures are high, fluid passes out of the capillaries into the interstitial space and **edema** or

- Most of the **prostaglandins** are vasodilator agents though **some of the prostaglandins are vasoconstrictor.**

**FTB**

- During emotional rage such as apprehension and rage vasodilation occurs due to secretion of epinephrine.
- It is a hormone that is responsible for fear, flight and fright conditions.
- The sympathetic vasodilator fibres are part of a regulatory system that originates in cerebral cortex and ends at postganglionic neurons in blood vessels on skeletal muscles, activate them to release acetylcholine, and vasodilation occurs.
- Blood discharge through thoroughfare channels rather than capillaries so heat loss occurs and the skin becomes hot and red.
- While in vasoconstriction blood supply becomes less to skin, so heat is preserve and the skin becomes cold.
- Situations such as shock, hypertention and tachycardia occur by stimulation of arterial stretch receptors and production of hypertension and bradycardia occur by increased intracranial pressure.

## ROLE OF PRECAPILLARY SPHINCTER IN REGULATING THE FLOW OF BLOOD

- At the point where true capillaries originate from the metarterioles a smooth muscle fibre usually encircles the capillary. This is called precapillary sphincter
- This sphincter can open and close the entrance to the capillary.
- Precapillary sphincters are normally either completely open or completely closed, and the degree of constriction of the metarteriole also varies.
- The number of precapillary sphincters that are open at any given time is about proportional to the requirements of the tissue for nutrition.
- In addition the precapillary sphincters and metarterioles often open and close cyclically several times per minute, with the duration of the open phases being about proportional to the metabolic needs of the tissue.
- The cyclic opening and closing is called vasomotion.

## ROLE OF PRECAPILLARY SPHINCTER IN REGULATING THE FLOW OF BLOOD

Cardiovascular system includes **two circuits:**

**PULMONARY CIRCUIT:**

The pulmonary circuit which circulates blood through lungs.

**SYSTEMIC CIRCUIT:**

Systemic circuit which circulates blood to all other parts of the body.

## PULMONARY CIRCULATION

The path of blood through the lungs can be traced as follows:

- The left atrium receives oxygenated blood from the lungs through a pair of pulmonary veins, which open by common aperture into it.

fluid accumulation is resulted.

- The average pressure in the veins is only 8-10 mm Hg (In arteries It is 100mm Hg).
- The Veins have a very low pressure of blood which is not sufficient to take the blood to the heart, they keep valves which allow the flow of blood in one direction towards heart and prevent back flow.
- Venules (8-100 micrometer in a diameter) after coming out of tissues start joining with each other to make veinlets and larger veins.
- It has been estimated that an adult human being has some **60,000 miles of capillaries with a total surface area of some 800-1000 m²** (an area greater than three tennis courts).





- From left atrium the blood flows into the left ventricle.
- The superior and inferior vena cavae bring deoxygenated and open into the right atrium.
- From right atrium blood flows into the lungs for oxygenation by a pulmonary arch or trunk which divides into two pulmonary arteries, each going to the lung of its own side.
- This part of circulation is called pulmonary circulation or circuit. The pulmonary arteries carry deoxygenated blood and pulmonary veins carry oxygenated blood.

## SYSTEMIC CIRCULATION

- The systemic circuit includes all the arteries and veins other than involved in pulmonary circuit.
- The largest artery in the systemic circuit is the **aorta** and the **largest veins are the superior and inferior venae cavae.**
- The path of systemic blood to any organ in the body begins in the left ventricle which pumps blood in the aorta.
- Branches from aorta go to the organs and major body regions.
- The superior vena cava collects blood from the head and the chest and the arms and the inferior vena cava collects blood from the lower body regions.
- Both enter the right atrium. The aorta and the vanaecavae are the major pathways in the systemic circuit.
- In most instances the artery and the vein that serve the same organ are given the same name.

## CORONARY CIRCULATION

- The wall of the heart has its own supply of blood vessels to meet its vital needs.
- The myocardium is supplied with blood by the right and left coronary arteries
- From the capillaries in the myocardium, the blood enters the cardiac veins.
- The course of these vessels parallels that of the coronary arteries.
- These cardiac veins converge to form the coronary sinus channel on the posterior surface of the heart.
- The coronary venous blood then enters the heart through an opening into the right atrium.

## HEPATIC PORTAL SYSTEM

- Blood from the capillaries within most of the abdominal viscera such as the stomach, intestines, and spleen drains through a specialized system of blood vessels to the liver.
- Within the liver the blood flows through a **series** of dilated capillaries called sinusoids.
- A portal (meaning door) system is vascular system that begins and ends with capillary beds and has no pumping mechanism such as the heart.
- The portal system that begins with capillaries in the viscera and ends with the sinusoidal capillaries in the liver is the hepatic (meaning, relating to the liver) portal system.

**BTB**

- Liver has the most abundant blood supply with approximate blood flow of **1350ml/min**. Kidneys and brains are second and third most supplied organs with **1100** and **700 ml/min** respectively.

- The hepatic portal vein, the largest vein of the system, is formed by the union of the superior mesenteric vein, which drains the small intestine and the splenic vein, which drains the spleen.
- The splenic vein receives the inferior mesenteric and pancreatic veins, which drain the large intestine and pancreas, respectively.
- The hepatic portal vein also receives gastric veins before entering the liver. Blood from the liver sinusoids is collected into central veins, which empty into hepatic veins.
- Blood from the cystic veins also enters the hepatic veins. The hepatic veins join the inferior vena cava.

## RENAL CIRCULATION

- Arterial blood enters the kidney at the hilum through renal artery, which divides, into **interlobular arteries, arcuate arteries branch from the interlobular arteries at the boundary of renal cortex and renal medulla.**
- Small interlobular arteries radiate from the arcuate arteries and project into the renal cortex.
- Microscopic afferent glomerular arterioles arise from the branches of the interlobular arteries.
- From here blood enters either the peritubular capillaries or vasa recta. From these capillary networks the blood is drained into interlobular
- veins and arcuate veins. which leave the kidney as a single renal vein.

## RATE OF BLOOD FLOW IN BLOOD VESSELS

- Blood flow means simply the quantity of blood that passes through a given point in the circulation in a given period.
- Ordinarily, blood flow is expressed in **milliliter or liter per minute**, but can be expressed in milliliter, per second or any other unit of flow.
- The over all blood flow in the circulation of an adult at rest is about **5000 ml/min**. This is called **cardiac output**.
- **Cardiac output** is the amount of blood pumped by the heart in a unit period.
- **The velocity** of blood flow is greatest in the aorta, but the **total cross-sectional area** for the capillaries is large, but the velocity of blood flow is low.
- As the veins become larger in diameter, their total cross-sectional area decreases, and the velocity of blood flow increases.
- The relationship between blood vessel diameter and velocity of blood flow is much like a stream that flows rapidly through a narrow gorge, but flows slowly through a broad plane.

| ARTERIES | VEINS | CAPILLARIES |
|---|---|---|
| 1. These transport blood away from the heart to the various parts of the body through capillaries. | 1. These collect blood from body through capillaries and transport it towards heart. | 1. These link arteries with veins. |
| 2. All arteries carry oxygenated blood except pulmonary arteries. | 2. All veins carry deoxygenated blood except pulmonary veins. | 2. These have mixed oxygenated and deoxygenated blood. |
| 3. There are no valves in them except at the base of pulmonary trunk and aorta. | 3. Valves are present. These prevent the back flow of blood. | 3. There are no valves. |
| 4. Have high blood pressure. | 4. Have low blood pressure. | 4. Falling pressure in these |





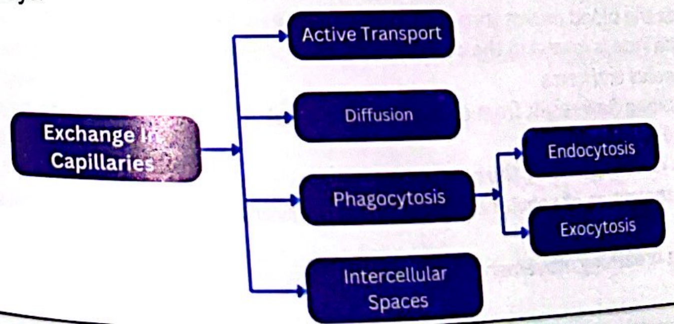
| | | |
|---|---|---|
| 5. Wave of blood pressure or pulse due to heartbeat can be detected. | 5. No pulse. | 5. No pulse |
| 6. Blood flow rapid. 400-500mm per second in aorta and decreasing in arteries and arterioles. | 6. Rate of blood flow increases from smaller to larger veins. | 6. Blood flow slowest less than 1mm per second. |
| 7. Have smaller bore and thick wall. | 7. Have larger bore and thin walls. | 7. Larger bore; wall one cell in thickness. |
| 8. Thick muscle layer and elastic fibers present. The elasticity helps changing the pulsating flow of blood. | 8. Thin muscle layer and less elastic fibers. So they are less elastic | 8. No muscle or elastic fibers. |
| 9. No exchange of materials. | 9. No exchange of materials. | 9. Responsible for exchange of materials. |

**BTB**

- There is a deposition of hard yellow fatty masses called **plaques**.
- **Calcium ions** also deposit in the plaque which loses (weakens) their elasticity and easily gets ruptured.

**PTB**

- **Atherosclerosis** (Greek. athere porridge; skeleoris hardening): It is coexisting atheroma and **arteriosclerosis**; atheroma is deposition of **hard yellow** plaque of **lipoid material** in the **inner most layer** of the arteries, which may be due to high level of cholesterol in the blood.
- **Arteriosclerosis** is a degenerative arterial change associated with advancing age. Primarily a thickening of **middle layer of arteries**, and usually associated with some degree of atheroma.
- So Atherosclerosis causes narrowing and hardening of arteries. This increases the risk of formation of thrombus (see thrombus formation), and if thrombus is formed in the brain or heart it is fatal
- Atherosclerosis is a major condition leading to heart attack.
- Capillaries are blood vessels with walls that are only one cell thick
- Although the blood appears confined within the capillary walls, the latter are permeable with the result, that water and dissolved substances pass in and out exchanging oxygen, carbon dioxide dissolved food and excretory products with the tissues around capillary.
- **In the liver**, every cell is in direct contact with a capillary.
- The diameter of a capillary can be altered by **nervous stimulation, which tends to close them, and by chemicals, such as histamine, which dilate them.**
- The change in diameter is brought about by a change in the shape of the cells, constituting their walls.
- The capillaries are the sites where the materials are **exchanged** between the blood and body tissues. This exchange occurs in three ways.



- **Active transport** and **diffusion** through the cells lining the capillary wall into the interstitial or extracellular fluid, and then to the body cells, and vice versa.
- Through the intercellular spaces of endothelial lining of wall of capillary to and from the extracellular fluid.
- **Materials** from the cavity of capillaries are also taken up by **endocytosis**, and then passed to the other side by **exocytosis**.
- Same is true for some materials entering from the interceullar spaces (extracellular fluid) into the blood. Thus the exchange of materials takes place between blood and tissues via **extracellular** or **interstitial fluid**.
- Capillaries join to form venules, which join to form veins.
- The wall of veins has same three layers as are present in arteries. But middle layer is relatively thin and only slightly muscular, with few elastic fibres
- Venules join to form larger veins, and ultimately form venae cavae (Inferior vena cava and superior vena cava) which pour the blood into the right atrium of the heart.
- The oxygenated blood from the lungs is brought to the left atrium by pulmonary veins.
- The pressure within capillaries causes a continuous leakage of fluid from the blood plasma into the spaces that surround the capillaries and tissues. This fluid, known as **interstitial fluid** consists primarily of water, in which the dissolved nutrients, hormones gases, wastes, and small proteins from the blood are present.
- **Large proteins red blood cells and platelets** cannot cross the intercellular spaces of capillary wall, so they remain within capillaries.
- But some white blood cells can squeeze out through the intercellular spaces of capillary wall.
- Interstitial fluid is the medium through which the exchange of materials between the blood and nearby cell occurs.
- **Systolic pressure** which in normal individuals is **120 mm Hg**) and its low point during diastole (diastolic pressure which in normal individuals ranges between **75-85 mm Hg**.
- The decline of the blood pressure in successive parts of systemic circuit, is the result of friction between the flowing blood and the walls of the blood vessels - thus blood moves from a region of higher pressure towards a region of lower pressure.
- Several other changes occur along the route of blood flow. **i)** The difference between systolic and diastolic pressure continues to diminish until it disappears in the capillaries and veins. **ii)** The rate of blood flow tends to fall as the blood moves through the branching arteries and arterioles, the **rate is lowest in the capillaries**; and increases again in the venules and veins.
- These changes in rate of blood flow result from changes in the total cross sectional area of the vessel system.
- The flow of blood in veins is maintained by the contraction of surrounding muscles and the action of semilunar valves which prevent back flow of blood.
- Muscular activity including breathing movements help normal flow of blood in the body.





## LYMPHATIC SYSTEM OF MAN


The lymphatic system includes lymph, lymphocytes, lymphatic vessels, lymph nodes, tonsils, spleen and thymus gland.

## INTERSTITIAL FLUID

- About **one sixth** of the body consists of spaces between the cells, which collectively are called the **interstitium.**
- The fluid in these spaces is the interstitial fluid or intercellular fluid.

### FORMATION

The fluid in the interstitium is derived by filtration and diffusion from the capillaries.

### COMPOSITION

It contains almost the same constituents as plasma except for much lower concentrations of proteins because proteins do not pass outward through the walls of the capillaries with case.

- The interstitial fluid is mainly **entrapped** in the minute space among the proteoglycan filaments.
- This combination of **proteoglycan** filaments and the fluid entrapped within them has the characteristics of gel and therefore is called tissue gel.

### FUNCTION

Instead of flowing fluid mainly diffuse through the gel. Diffusion through the gel occurs about **9[illegible] to 99 percent** as rapidly as it does through free fluid.

- For the short distances between the capillaries and the tissue cells, this diffusion allows rapid transport through the interstitium not only of water molecules but also of electrolytes, nutrients, cellular excreta, oxygen, carbon dioxide etc.
- Materials are exchanged between the blood and interstitial fluid and between the interstitial and the body cells.
- In other words, to get from the blood to body cells or vice versa, materials must pass through the interstitial fluid.

### COMPARISON

**BTB**

- Lymphatic System, is neither closed circulatory system nor does it have pump
- Lymph is colorless fluid which is derived form blood vessels (Blood plasma) and resembles to plasma in composition contains WBC (no RBC), contains large protein, which ultimately returns to the blood
- Lymph vessels have valves, which prevent backward flow of lymph.
- The lymphatic vessels of the legs join to lymph vessels of alimentary canal and then to form the thoracic duct which empties lymph into the left subclavian.
- Right Lymphatic duct drains lymph from the right anterior parts of the body and finally enters into the right branchiocephalic vein.

**KPK**

- The lymphatic system is a network of vessels found in vertebrates that carry a milky fluid called lymph.

- Approximately **30 litres** of fluid pass from the blood capillaries into the interstitial space each day, whereas only **27 litres** pass from the interstitial space back into blood capillaries.
- The remaining **3 litres** of fluid enters the lymphatic capillaries, where the fluid is called lymph (meaning clear spring water) and passes through the lymphatic vessels back to the blood.
- In addition to water lymph contains solutes derived from two sources: **(a)** substances in plasma such as ions, nutrients, gases and some proteins, pass from blood capillaries into the interstitial space and become part of the lymph and **(b)** substances derived from cells, such as hormones, enzymes and waste products are also found in the lymph.

## LYMPHATIC VESSELS

- The lymphatic system unlike the circulatory system only carries fluid away from tissue.
- The lymphatic system begins in the tissues as lymph capillaries, which **differ from capillaries as they lack a basement membrane.**
- The lymph capillaries are far more permeable than blood capillaries, and nothing in the interstitial fluid is excluded from the lymph capillaries, Second, the lymph capillary epithelium functions as a series of one-way valve that allows fluid to enter the capillary but prevent it from passing back into the interstitial spaces.
- The lymph capillaries join to form larger lymph vessels that resemble small veins.
- Small lymphatic vessels have **a beaded appearance** because of the presence of **one-way valves** along their lengths that are similar to the valves of veins.
- Lymph nodes are round, oval, or bean-shaped bodies distributed along the various lymphatic vessels.
- **The lymph nodes function to filter lymph.**

## THORACIC DUCT

- The thoracic duct drains the lower limbs, abdomen, the left thorax, the left upper extremity, and the left side of the head and neck
- The duct ends by entering the left **subclavian vein.**

## LYMPHATIC DUCT

- The right lymphatic duct is much short and smaller in diameter than the thoracic duct.
- It drains the right thorax, right upper limb, and right side of the head and neck and opens into the right subclavian vein.

## ROLE OF LACTEAL PRESENT IN VIL

- Each villus contains a lymph capillary called lacteal.
- The lymphatic system absorbs fats and other substances from the digestive tract.
- Fat enters the lacteals and pass through these lymphatic vessels to venous circulation.
- The lymph passing through these lacteals has a milky appearance because of its fat contents.

- In 1652 the lymphatic duc... the liver were f... described by a **Swedish OlausRudbeck** (1630-1702) and ... very next year ... Thomas Bartho... who described ... vessels in the wh... body and appen... gave them the na... of Lymph vessels ... certain points, ha... masses of connective tissues called lymph node... These node (**more than 100 in human body**) are present ... the armpits, groin and neck region.
- These are the sites of lymphocyte production and storage.
- They are distributed throughout the body, but they lack the tissues of the **central nervous system.**



- Chylomicrons (these are proteins, triglycerol **90%** phospholipids **4% and cholesterol 5%**) enter the lacteal.
- Chylomicrons enter the lymph capillaries because lymph capillaries lack basement membrane and are more permeable to large particles.

## LYMPH NODES

- Lymph nodes are small, round or bran-shaped structures, ranging in size from **1 to 25 mm** long, and are distributed along the course of the lymphatic vessels.
- They filter the lymph, remove bacteria and other materials.
- In addition, lymphocytes congregate (assemble), function and proliferate within lymph nodes.
- Lymph nodes are found throughout the body.

## SPLEEN

The spleen, which is roughly the size of a clenched fist, is located on the left side in the extreme superior, posterior part of the abdominal cavity.

- The spleen detects and responds to foreign substances in the blood, destroys worn-out erythrocytes, and acts as a blood reservoir.
- Foreign substances in the blood passing through the white pulp can stimulate lymphocytes in the periarterial sheath or the lymph nodules in the same manner as in lymph nodes.
- Before blood leaves the spleen through veins, it passes into the red pulp.
- Macrophages in the red pulp remove foreign substances and worn-out erythrocytes through phagocytosis.
- In emergency situations such as haemorrhage, smooth muscle in splenic blood vessels and in the splenic capsule contract in response to sympathetic stimulation.
- The result is the movement of a small amount of blood from the spleen into the general circulation.

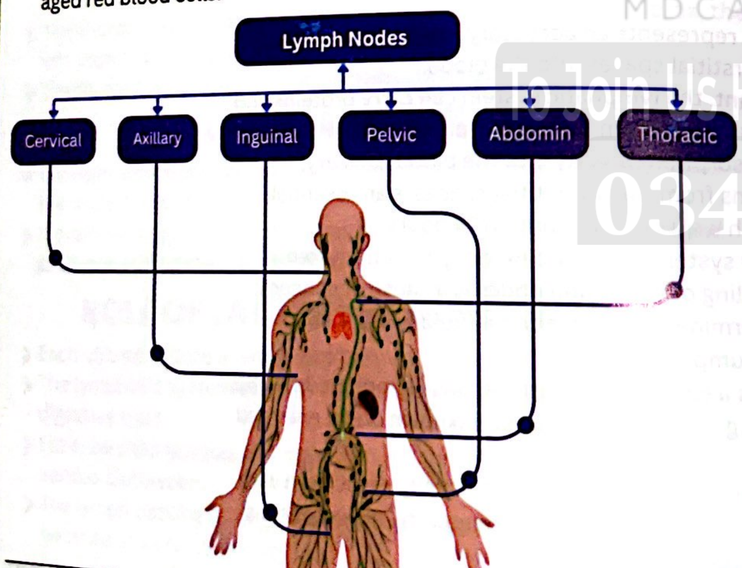
**FTB**

- The lymphatic system represents an accessory route by which fluid can flow form the interstitial spaces into the blood.
- And, the most important, the lymphatic system can carry proteins and large particulate matter away from the tissue spaces, neither of which can be removed by absorption directly into the blood capillary.
- This removal of proteins from the interstitial spaces is an essential function, without which we would die with- in 24 hours.
- Thus blood circulatory system is dependent on lymphatic system. Interpret why the swelling of the lymph nodes is a cause of concern.
- Lymphatic flow is determine by the interstitial fluid pressure and activity of lymphatic pump.
- Lymph node swelling is a cause of concern because lymph node swells in different diseases, e.g. in pyrexia (fever) of unknown origin enlarged lymph nodes appear.
- Enlargement of anterior and tonsillar nodes is usually associated with tonsillitis or pharyngitis, posterior lymphoadenopathy may suggest a glandular fever syndrome or HIV in- fection.

- The causes of lymphoadenopathy (swelling of lymph node) are bacterial (streptococcal, tuberculosis), viral, protozoal, fungal (histoplas- mosis), leukeemias, lymphomas etc

**PTB**

- This system is responsible for the transport and returning of materials from the tissues of the body to the blood.
- Lymph capillaries **end blindly in the body** tissues, where pressure from the accumulation of interstitial fluid or extracellular fluid forces the fluid into the lymph capillaries.
- lymph is a fluid in **transit** between interstitial fluid and the blood.
- The flow of lymph is always towards the thoracic duct.
- In the intestine, the branches of lymph capillaries, within villi, are called lacteals.
- **The flow of lymph is maintained** by: Activity of skeletal muscles, movement of viscera, breathing movements and the valves, which prevent back flow of lymph.
- **Several afferent lymph** vessels enter a lymph node, which is drained by **a single efferent** lymph vessels.
- Lymph nodes are present in the neck region, axilla and groin of humans.
- In addition, several lymphoid masses are present in the walls of digestive tract, in the mucosa and submucosa.
- The larger masses spleen and thymus, tonsils and adenoids are all lymphoid masses. These produce lymphocytes
- After a fatty meal these fat globules may make up **1%** of the lymph
- The painful swelling of lymph nodes in certain diseases **(mumps is an extreme example)** is largely a result of the accumulation of dead lymphocytes and macrophages
- Just as the lymph nodes filter lymph, the spleen filters blood, exposing it to macrophages and lymphoctyes that destroy foreign particles and aged red blood cells.






The nodes are mostly located in following six areas:

- **The cervical region:** Nodes in this area are grouped along the lower border of the jaw, in front of and behind the ears, and deep in the neck along the larger blood vessels. They drain the skin of the scalp, face, tissues of the nasal cavity, and the pharynx.
- **The axillary region:** These nodes are in the underarm region and receive lymph from vessels that drain the arm, the walls of the thorax, the breast, and the upper walls of the abdomen.
- **Inguinal region:** The nodes in this area receive lymph from the legs, the outer portion of the genitalia and the lower abdominal wall
- **The pelvic cavity:** The nodes here appear mostly along the paths of the blood vessels within the pelvic cavity and receive lymph from the lymphatic vessels in the area.
- **Abdominal cavity:** Within this area, nodes occur in chains along the main branches of the arteries of the intestine and the abdominal aorta
- **Thoracic cavity:** These nodes occur between the lungs and along the windpipe and bronchi, and receive lymph from this area and from the internal wall of the thorax.

## DISEASES OF LYMPHATIC SYSTEM

- Problems with the system can impair the body's ability to fight infections. **Hodgkin's disease** is an enlargement of the lymph nodes in the neck.
- Pressure on adjoining organs and nerve endings can result in a dysfunction of vital organs or in paralysis

| | BLOOD CAPILLARIES | | LYMPH CAPILLARIES |
|---|---|---|---|
| 1 | These are reddish and easy to locate. | 1 | These are colorless, thus difficult to locate. |
| 2 | These are joined to arterioles at one end and to venules at the other end. | 2 | These are joined to arterioles at one end and to venules at the other end. |
| 3 | These have no free end. | 3 | Their free ends are blind and expanded into a knob. |
| 4 | These are narrower than lymphatic capillaries. | 4 | These are wider than blood capillaries. |
| 5 | These have a uniform diameter. | 5 | These are not of uniform thickness. |
| 6 | These carry blood received from arterioles to the venules. | 6 | These carry colorless lymph received from tissue spaces by lymphatic vessels. |
| 7 | Blood flows through them under high pressure. | 7 | Lymph flows through them under low pressure. |
| 8 | Provide tissue fluid to intercellular spaces. | 8 | These absorb tissue fluid from intercellular spaces. |

| | BLOOD | | LYMPH |
|---|---|---|---|
| 1 | It is a red fluid tissue. | 1 | It is a colorless fluid tissue. |
| 2 | It circulates and flows through the arteries, capillaries and veins. | 2 | It flows in the tissue-spaces and through the lymphatic capillaries and vessels enter the subclavian veins. |
| 3 | It consists of erythrocytes leucocytes and platelets. | 3 | It consists of leucocytes only. |

| | | | |
|---|---|---|---|
| 4 | It appears red because of the presence of erythrocytes. | 4 | Due to the absence of erythrocytes it appears colorless. |
| 5 | It is rich in plasma proteins, calcium and phosphorus. | 5 | It has fewer plasma proteins and less calcium and phosphorus. |
| 6 | It flows rapidly. | 6 | Its flow is very slow. |



CHAPTER 11

# IMMUNITY

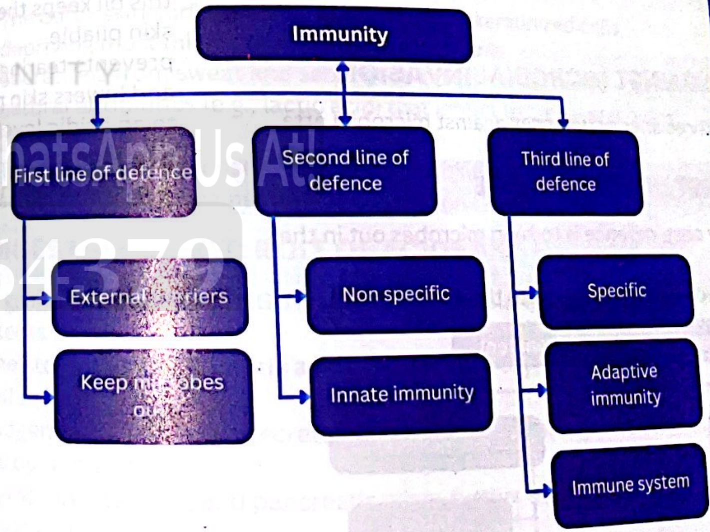
## Immunity

- "The capacity to recognize the intrusion of any foreign material to body & to mobilize cells and cell products to help remove particular sort of foreign material with greater speed & effectiveness"

OR

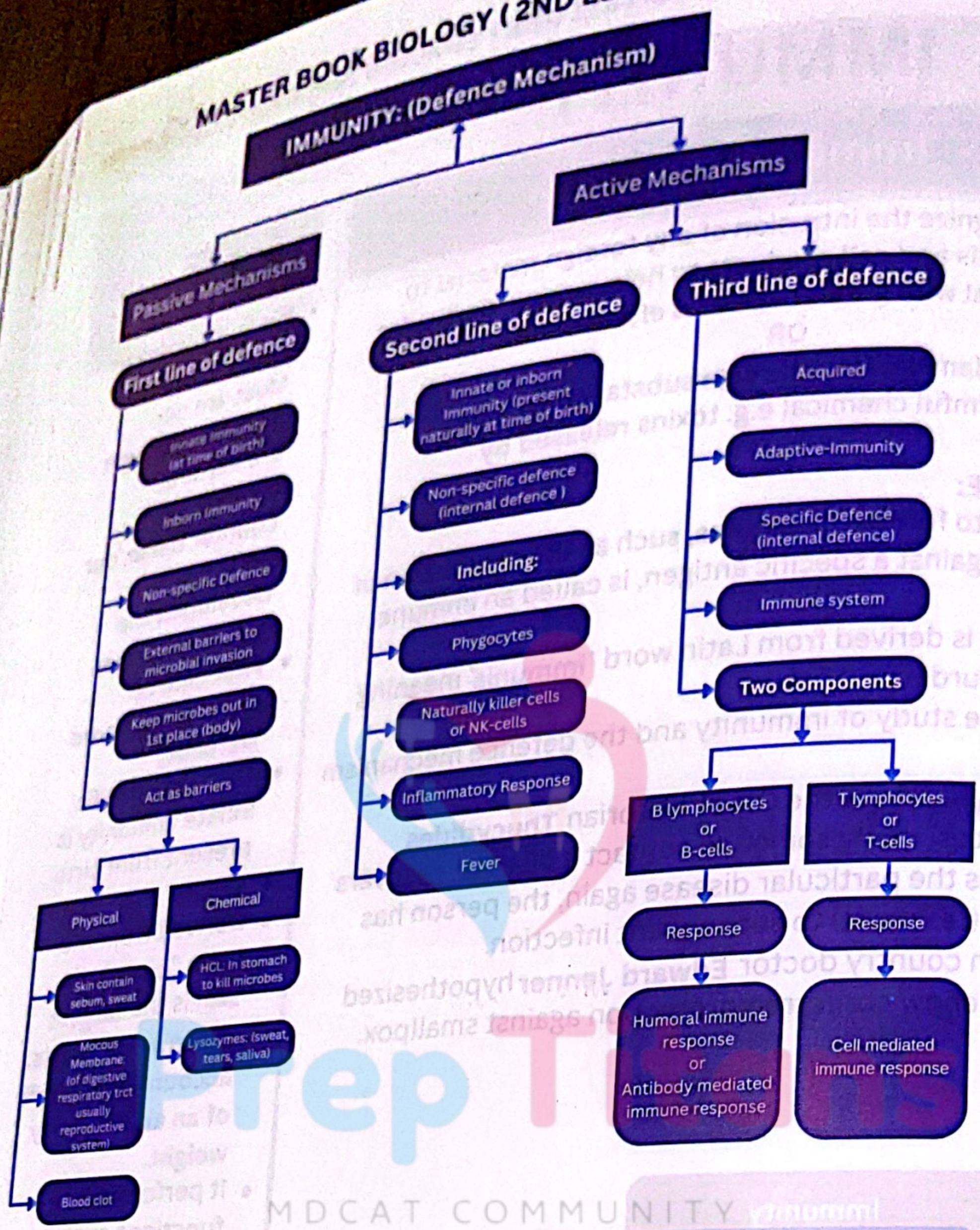
- "The Ability to resist damage from foreign substance such as microorganisms & harmful chemical e.g. toxins released by microorganisms."

- **IMMUNE RESPONSE:**
- The body's response to foreign molecules, such as the production of antibodies directed against a specific antigen, is called an immune response.
  - The term immune is derived from Latin word '**immunis**' meaning "**safe**" or free of burden.
  - **Immunology** is the study of immunity and the defence mechanism of the body.
  - More than **2000 years ago**, the Greek historian **Thucydides** observed that occasionally someone contact a disease, recovers and never catches the particular disease again, the person has become immune (resistant) to subsequent infection.
  - In **1796** an English country doctor **Edward Jenner** hypothesized that cowpox somehow conferred protection against smallpox.




**BTB**

- We live in a sea of micro-organisms. Most are our friends, but some are harmful invaders. To counter these, our body has developed the **immune system.**
- **First Line of Defence (Layered Defence)**
- This non-specific, innate immunity is present from birth.
- **Skin;**
- Derived from the Latin "**cutis**," the skin is the **largest organ in mammals, accounting for 15% of an adult's body weight.**
- It performs functions such as protection, sensation, heat regulation, evaporation control, and excretion.
- The dermis produces oil (via sebaceous glands) and sweat (via sweat glands), creating a skin surface **pH of 3 to 5**—acidic enough to inhibit many micro-organisms.
- Sweat also contains lysozymes that digest

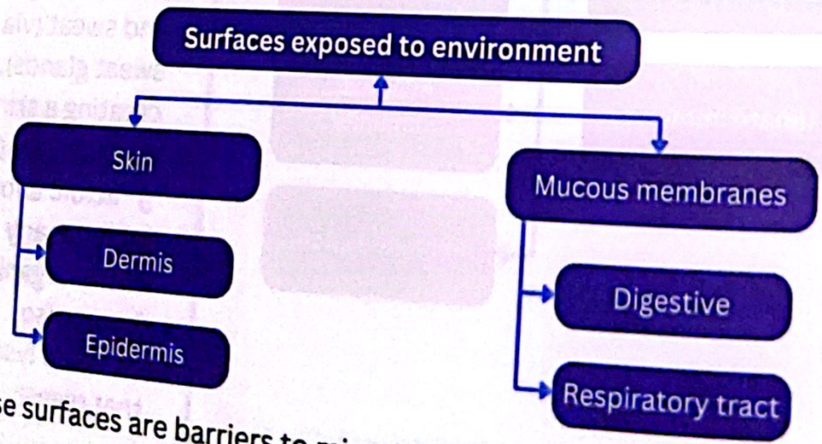



## DEFENCES AGAINST MICROBIAL INVASION

- The human body has three lines of defences against microbial atta.

## FIRST LINE OF DEFENCE

- The first and obviously best, defence is to keep microbes out in the first place.
- The human body has two surfaces exposed to the environment.

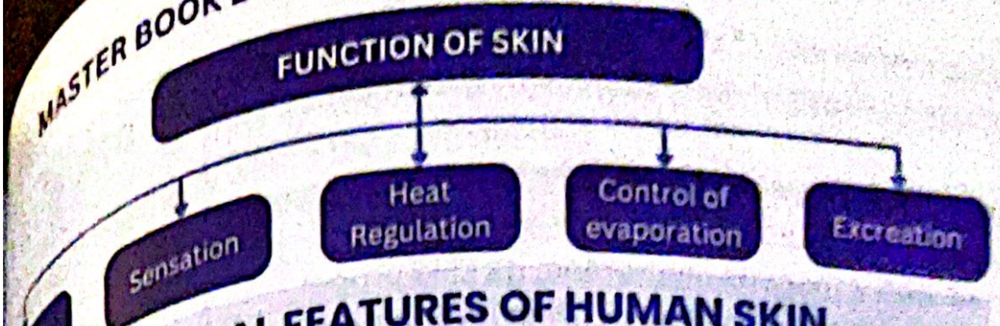



- These surfaces are barriers to microbial invasion.

cell walls and natural antibio... like lactic acid

**KPK**

- The skin is the largest organ of the integumentary system.
- The dermis, located beneath the epidermis, contains protein fibers called collagen.
- Collagen is a tough, fibrous protein that gives the skin strength and pliability, helping it resist abrasions that could allow microorganism entry.
- Sebum is secreted by the skin's sebaceous glands; this oil keeps the skin pliable, prevents tearing and lowers skin p... to an acidic level that inhibits bacterial growth.




## STRUCTURAL FEATURES OF HUMAN SKIN

The skin is made up two-layers dermis and epidermis.

**DERMIS:**

- The dermis is dense, irregular connective tissue.
- Nerve endings, hair follicles, smooth muscles, glands, and lymphatics extend into the dermis.

**EPIDERMIS:**

- The epidermis is a stratified squamous epithelium separated from the dermis by a basement membrane.
- Most epidermal cells are **keratinocytes**, which produce keratin.
- Other cells include **melanocytes** (contributing to skin color) and Langerhans cells (part of the immune system).

**GLANDS:**

The major glands of skin are the sebaceous glands.

- **Sebaceous glands**, located in the dermis, are simple or compound alveolar glands that produce sebum—an oily, white, lipid-rich substance.
- Most sebaceous glands connect via ducts to the upper part of hair follicles, oiling both the hair and skin surface, which prevents drying and provides protection against bacteria.
- There are **two types of sweat glands:** merocrine and apocrine.
- Intact skin forms a barrier against microbial entry and creates an inhospitable environment for microbial growth.
- The outer skin surface consists of dry, dead, keratinized cells, depriving most microbes of water and nutrients.
- Secretions from sweat and sebaceous glands contain acids and natural antibiotics (e.g., lactic acid) that inhibit bacterial and fungal growth.
- These multiple defenses make unbroken skin an extremely effective barrier against microbial invasion.



## DIGESTIVE TRACT: ROLE OF ACIDS AND ENZYMES

- The gastrointestinal tract (GIT) is lined by a mucous membrane that protects it.
- In the stomach, **hydrochloric acid** is secreted by oxyntic (parietal) cells to kill microorganisms.
- Zymogen (principal) cells secrete gastric enzymes that digest food and destroy microbes.
- Enzymes in intestinal and pancreatic juices further digest any remaining microorganisms.

## ROLE OF RESPIRATORY TRACT

- The nas

- Air contacts the mucous membrane of the nasal cavity, which consists of pseudostratified ciliated columnar epithelium with goblet cells that secrete mucus.
- This mucus traps debris; the cilia sweep it posteriorly to the pharynx, where it is swallowed and eliminated by the digestive system.
- The trachea is also lined with a mucous membrane; its cilia propel mucus and trapped particles toward the larynx, then into the pharynx to be swallowed.
- In the bronchus and bronchioles, cilia and mucus serve as clearing mechanisms.

**FTB**

- The nasal turbulence mechanism is so effective that nearly no particles **larger than 6 micrometres** enter the lungs through the nose.
- Many particles between **1 and 5 micrometres** settle in the small bronchioles due to gravitational precipitation.
- Particles smaller than **0.5 micrometres** remain suspended in alveolar air and are eventually expelled by expiration.

## SECOND LINE OF DEFENCE– THE NONSPECIFIC DEFENCES

- **SECOND LINE OF DEFENCE-** The non-specific defence internal
- defence (innate immunity) that combat all invading organisms.
  - **Three nonspecific internal defences** are mustered against microbes that penetrate the skin or mucous membranes.
  - These defences are nonspecific because they attack wide variety of microbes, rather than targeting specific invaders as the immune response does.
- **COURSE OF ACTION OF 2ND LINE OF DEFENCE:**
  1. Firstly, the body has a standing army of phagocytic cells that destroy microbes and natural killer cells that destroy cells of the body that have been infected by viruses.
  2. Second, an injury with combination of tissue damage and relatively massive invasion of microbes provokes an inflammatory response.
  3. Third, if a population of microbes proceeds in establishing a major infection, the body often produces fever, which slows down microbial production and enhances the body's own fighting abilities.

## KILLING CELLS OF BLOOD

- Constantly patrolling your body are white cells called phagocytes.
- A phagocyte is a cell that destroys other cells by engulfing and ingesting them. This process is called **phagocytosis.**
- Two types of blood cells are phagocytes:
  1. Macrophages
  2. Neutrophils.

## MACROPHAGES

- Monocytes are formed in bone marrow. Monocytes have short life i.e. only **10-20 hours.**
- Macrophages are derived from monocytes or the monocytes that that

**BTB**

- Second Line of Defence is also a part of innate immune system.
- Although the surface defences of the vertebrate body are very effective but occasionally breached allowing invaders to enter the body.
- At this point the body uses a host of non-specific cellular and chemical devices to defend itself.
- This type of defence is referred as second line of defence.
- All these devices have one common property i.e., they respond to any microbial infection without pausing to determine the invader's identity.
- Killing cells of blood Perhaps the most important of vertebrate body's non-specific defence are the white blood cells called **leucocytes.**
- The macrophages (**Big eaters**) are large irregularly shaped cells that kill microbes by ingesting them through phagocytosis (like Amoeba).

...that leave the blood are called macrophages.
From bone marrow, through blood, macrophages are transported to the areas of the body where they are needed.

**MICROPHAGES FOUND IN**

- Lungs
- Liver
- Spleen
- Kidney
- Nodes

- Macrophage can engulf large particles, even the whole red blood cells, or occasionally even malarial parasites.
- Macrophages after digesting particles can extrude the residual products.
- Macrophages are beneath the free surfaces of the body and provide protection by trapping and destroying microorganisms entering the tissue.

**ROLE OF MACROPHAGES:**

- The macrophages secrete many different proteins.
- Some of these proteins trigger the maturation of monocytes into macrophages, thereby increasing their numbers.
- Another protein **interleukin-1 signals** the brain to raise the body temperature, producing fever.
- The higher temperature aids the immune response and inhibits the growth of invading microorganisms.

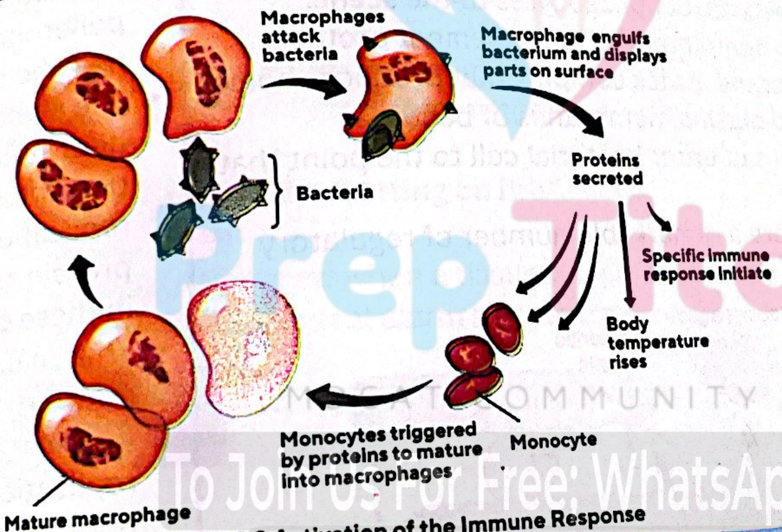



**Figure 13.3 Activation of the Immune Response**



## NEUTROPHILS

- These are a type of **granular leukocytes**, which are mobile and squeeze between cells of capillary walls.
- They move like **Amoeba forming pseudopodia.**
- The life of neutrophils once released from the bone marrow is **4-8 hours** circulating in blood and **4-5 days in tissue.**

**ROLE OF NEUTROPHILS:**

- In serious infections, life span is shortened to few hours, because they proceed rapidly to infected area to perform their duty and they often die after a single phagocytic event.
- Neutrophils also release lysosomal enzymes that kill microorganisms and also cause damage and inflammation.

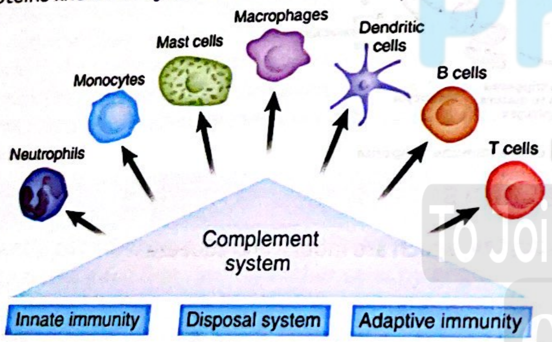
- **Neutrophils have short life span, after killing and digesting some pathogens they die.**
- Neutrophils are most abundant types of WBCs in most mammals, about **40 to 70%**
- **NK Proteins** called **perforins** are released from the membrane of the natural killer cells and inserted into membrane of target cell which then swell and bursts, by a protease (enzyme).
- The natural killer cells cause very effective defence against cancer cells usually before the formation of malignant tumor.

## NATURAL KILLER CELLS

- Natural killer cells are another class of white blood cells.
- In general, natural killer cells do not directly attack invading microbes.
- Instead, natural killer cells strike at the body's own cells that have been invaded by viruses.
- Virus infected cells usually bear some viral proteins on their surfaces, Natural killer cells recognize and kill cancerous cells.
- **COURSE OF ACTION:**
- Natural killer cells do not eat their victims, they strike from the outside. Their weapons are **proteins** that they secrete into the plasma membrane of the infected or cancerous cell.
- Killer cells also **secrete enzymes** that break up some of the molecules of the target cell, as a result the target cell soon dies.

## PROTECTIVE PROTEINS

- The complement system often simply called complement is a number of plasma proteins.
- Once a complement protein is activated, it activates another protein, and the result is a set series of reactions.
- Complement is activated when microbes enter the body.
- It "complements" certain immune responses and this accounts for its name.
- For example, it is involved in and amplifies the inflammatory response because complement proteins attract phagocytes to the scene.
- Another series of reaction is complete when complement proteins **(perforin-1)** result in a membrane attack complex that produces holes in the bacterial cell walls and plasma membranes of bacteria.
- When $K^+$ ions leave fluids and salt enter bacterial cell to the point that it bursts.
- Cells of immune system secrete a remarkable number of regulatory proteins known as **cytokines.**




## INTERFERONS

- When infected by viruses, cells respond by secreting cytokines called **interferons.**
- Interferons are a **heterogeneous group** of lipoproteins.
- They inhibit the growth of viruses by blocking the translation of viral proteins.

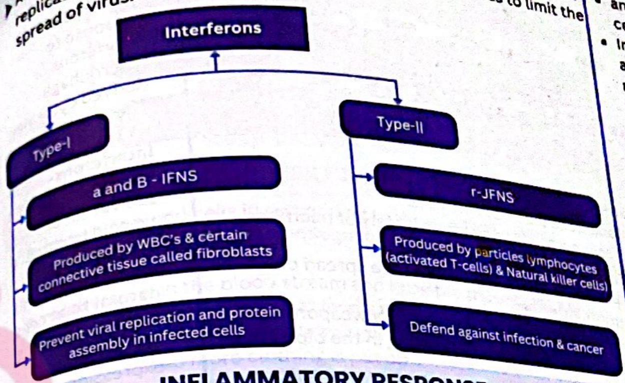
**BTB**

- There are three major categories of interferons. These are grouped into two types.
- **Type I,** alpha and beta while type II **is gamma.**
- These cells of the body synthesize alpha and beta interferons.
- These polypeptides act as messengers that protect normal cells in the vicinity of infected cells from becoming infected.
- Though viruses are still able to penetrate the neighbouring cells.
- The **alpha and beta** interferons prevent viral replication and protein assembly in these cells.
- Thus, named interferons means interfere with viral replication inside body cell.
- **Gamma interferon** is produced only by particular lymphocytes and natural killer cells.
- These interferons defend against infection and cancer.
- These also activate other immune cells such as macrophages



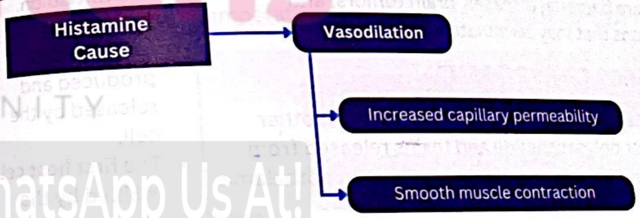


- As interferons are produced within a few hours of the initiation of viral replication, they may act in the early phase of viral diseases to limit the spread of virus.




## INFLAMMATORY RESPONSE

- The inflammatory response is a major component of the non-specific defence.
- Any damage to tissue, whether caused by an infection, microorganism or by physical injury, even just a scratch or an insect bite triggers this response.
- Inflammation can be localized or systemic.
- Local inflammation is an inflammatory response confined to a specific area of the body.
- Inflammation literally means **"setting on fire".**
- **COURSE OF ACTION:**
- The first thing that happened when a tissue is injured is that the damaged cells release chemical alarm signals such as **histamine.**

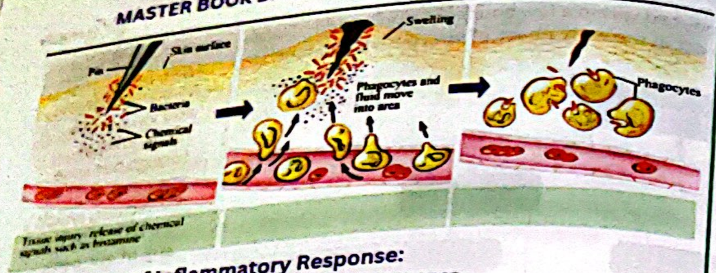



- The chemical sparks the mobilization of various defences.
- Histamine for instance induces neighbouring blood vessels to dilate and blood vessels start leaking.
- Blood flood to the damaged area increases, and blood plasma passes out of the leaky vessels into the interstitial fluid of the affected tissues.
- The major results of the inflammatory response are to disinfect and clean injured tissues.
- The white blood cells mustered into the area engulf bacteria and the remains of the body cells killed by them or by the physical injury are left.

- and natural killer cells.
- Invading bacteria and viruses are recognized as foreign because they contain molecules, which are different from any of our own molecule. These foreign molecules are known as **antigens.**
- **Histamine** secreted from basophils and **mast cells** which are a class of WBC. These cells are filled basophil granules found in number of tissues.

**KPK**

- **2ND LINE OF DEFENCE:**
- If you get a splinter or a cut, neutrophils will be attracted by a process called **chemotaxis**
- **NK cells** play a major role in the host-rejection of both tumours and virally infected cells.
- The distinction between apoptosis and cell lysis is important in immunology - lysing a virus-infected cell would only release the virions, whereas apoptosis leads to destruction of the




- **Outcomes of Inflammatory Response:**
- Many of the white blood cells die in the process.
- The pus that collects around a wound consists largely of microbes, tissue debris and living and dead white blood cells.
- The inflammatory response also helps to prevent the spread of infection to the surrounding tissues.
- The body may react with one or several inflammatory weapons for instance the number of white blood cells circulating in the blood may increase.
- Another response is fever.

**SIGNS OF INFLAMMATION**

- Heat
- Pain
- Swelling
- Redness
- Loss of function

## TEMPERATURE RESPONSE

- **Fever,** which means a body temperature above the usual range of normal, can be caused by abnormalities in the brain itself or by toxic substances that affect the temperature-regulating centres.
- Some causes of fever are bacterial diseases, brain tumors, and environmental conditions that may terminate in heatstroke.

## EFFECT OF PYROGENS

- Many proteins, breakdown products of proteins, and certain other substances, especially lipopolysaccharide and toxins released from bacterial cell membranes, can cause the set-point of the hypothalamic **thermostat** to rise.
- Substances that cause this effect are called **pyrogens.**
- It is pyrogens released from toxic bacteria (**exo-pyrogens**) or pyrogens released from degenerating tissues of the body(**endo-pyrogens**) that cause fever during disease conditions.
- When the set point of the hypothalamic temperature-regulating centre becomes increased to a higher level than normal, all the mechanisms for raising the body temperature are brought into play, including heat conservation and increased heat production.
- Within a few hours after the set- point has been increased to a higher level, the body temperature also approaches this level.

virus inside

- NK cells are activated in response to interferons or macrophage-derived cytokines.
- These activities co-ordinated by **Interferons-mediated activation** of certain immune cells, such as macrophages and natural killer cells and by enhancing cell surface expression of important immune molecules including major histocompatibility complex classes I and II, which display foreign (microbial) peptides for activation of T cells.
- Interferons genes of the cell's DNA are turned on.
- Interferon molecules are produced and released by the cell.
- **The first host cell is killed by the virus.**
- Many proteins, breakdown products of proteins, and certain other substances, such as lipopolysaccharide toxins (**LPS or endotoxin**)





**Benefits of fever**

- More antibodies produced that attack exact type of invades
- More WBCs produced, circulating, mobilizing and armed to fight off invading bugs
- More interferons produced, increase temperature which directly kills microbes

## THE WAYS FEVER KILLS MICROBES

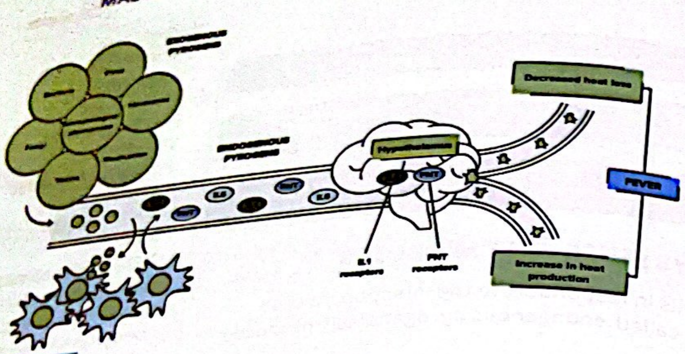
- Certain white blood cells in responding to the infection, release hormones collectively called **endogenous pyrogens** (self-produced fire makers).
- **Pyrogens** travel in the blood stream and raise the thermostat's set point, triggering behaviours that increase body temperature:
  1. Shivering increased fat metabolism
  2. Feeling cold so more clothing is put on.
- Pyrogens also cause other cells to reduce the concentration of iron in the blood.
- Fever has both beneficial effects for the body's defences and detrimental effects on the invading microbes.
  1. Many bacteria **require more iron** to reproduce at temperature of **38°C or 39°C than at 37°C,** so fever and reduced iron in the blood combine to slow down their rate of reproduction.
  2. Simultaneously, fever **increases the activity of phagocytic white blood cells that attack bacteria,** they rely producing a shorter and less serious infection.
  3. When viruses invade certain cells of the body they synthesize and release a protein called **interferon.** It travels to other cells and increases their **resistance to viral attack.** Fever increases the production of interferons.
  4. The higher body temperature may directly inactivate the virus particles.

**Fever higher body temperature (then normal) Facilities / Activities**

- Microbial growth in body
- Phagocytic WBCs that attack upon bacteria
- Reduce conc. of iron in blood (bcz. many bacteria required more iron to reproduce at 38°C than at 37°C)
- Increase production of interferons (increase cell resistance to viral attack)
- Reduced viral replication

secreted by bacteria, can act as pyrogens

- Most potent pyrogens are the endotoxins produced from the cell walls of the **Gram-negative bacteria.**
- Then someone has a fever, the body raises the normal body temperature above **37.8°C (100°F)** to try to kill bacteria or viruses in the body (this temperature is taken orally).
- The two functions of fever are:
  1. To stimulate the immune system.
  2. To create an inhospitable environment for invading organisms.
  3. That is, to turn up the heat high enough that the invading microbes cannot live.
- **The Benefits of Fever**
- More antibodies cells trained to specifically attack the exact type of invader that your body is presently suffering from produced more specific to the agent of disease than any medicines.
- More white blood cells produced,




FTB

**ROLE OF INTERLEUKIN-1 AND PROSTAGLANDINS IN FEVER:**

- *Several experiments have suggested that **Interleukin-1** causes fever by first inducing the formation of one of the **prostaglandins**.*
- *When drugs block prostaglandin formation, the fever is either completely abrogated or at least reduced.*
- *In fact, this may be the explanation for the manner in which aspirin reduces the degree of fever because aspirin impedes the formation of prostaglandins from **arachidonic acid**.*
- *It also would explain why aspirin does not lower the body temperature in a normal person because a normal person does not have any interleukin-1.*
- *Drugs such as aspirin that reduce the level of fever are **called antipyretics**.*
- *The inflammatory response in arthritis as an example of a misdirected immune response.*
- *In this disease, **autoantibodies** are formed against **IgG** (antibody or immunoglobin of class G).*
- *These autoantibodies are called rheumatoid factors. The agent that induces these autoantibodies is unknown.*

*Within the inflamed joints, the synovial membrane is infiltrated with T cells, plasma cells and macrophages and the synovial fluid contains high levels of macrophage- produced inflammatory cytokines.*

circulating, mobilizing and armed to fight on the invading bug specific to the general category invader.

- More interferon produced which blocks spread of viruses to healthy cells.
- Walling off of iron which bacteria feed on. Increased temperature, which directly kills microbes.

## ANTIPYRETIC THERAPY

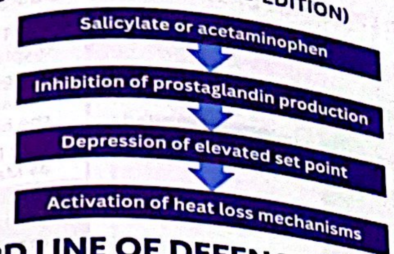
*Antipyretics create their effects by inhibiting prostaglandin production in the hypothalamus, which has the effect of blocking set point elevation and maintaining the set point at nearer normal levels.*

## PHARMACEUTICAL INTERVENTION IN FEVER

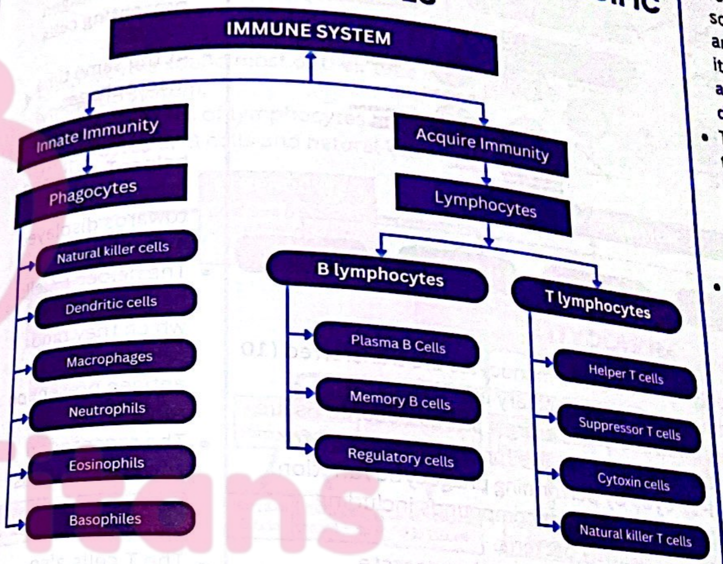
*The capacity to recognize the intrusion of any material foreign to the body and to mobilize cells and cell products to help remove the particular sort of foreign material with greater speed and effectiveness" is called **immunity**.*








## THE THIRD LINE OF DEFENCE- THE SPECIFIC DEFENCES

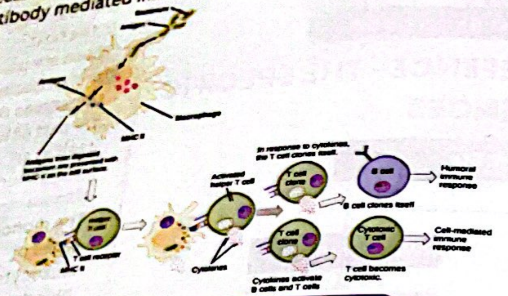


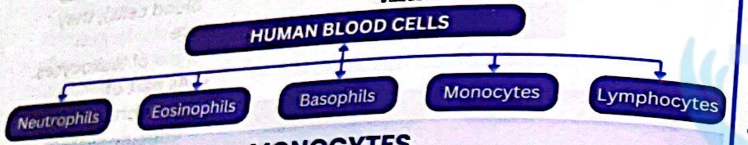

- The third line of defence or specific defence mechanism or immune system recognizes and defends against invading microbes and against cancer cells.
- Specific defence mechanisms depend on the lymphatic system and its cells.
- Substances that stimulate specific immunity are **antigens** (large molecules) and **haptens** (small molecules).
- Specific immunity historically has been divided into **two types:**
  1. Humoral immunity
  2. Cell-mediated immunity
- Early investigators of the immune system found that, when plasma from an immune animal was injected into the blood of a non-immune animal, the non-immune animal became immune. Because the process involved body fluids (humors), it was called **humoral immunity.**
- It was also discovered that blood cells transferred from an immune animal could be responsible for immunity and this process was called **cell-mediated immunity.**

BTB

- An antigen is a molecule capable of inducing an immune response in the host
- These are usually foreign bodies but sometimes these are part of host itself in an **autoimmune disease.**
- The monocytes are types of leukocytes (white blood cells), they are **the largest type** of leukocytes.
- As part of vertebrate innate immune system (discussed in second line of defence), monocytes also influence the process of adaptive immunity.
- There are at least two sub classes of monocytes in human blood.
- **Dendritic cells:-** These are antigen presenting cells, mark out foreign bodies to be e destroyed by lymphocytes
- **Macrophage Activation of T-Cells:**
- When infection occurs the T-cells particular antigen cells of invading micro-organism by engulfing it.

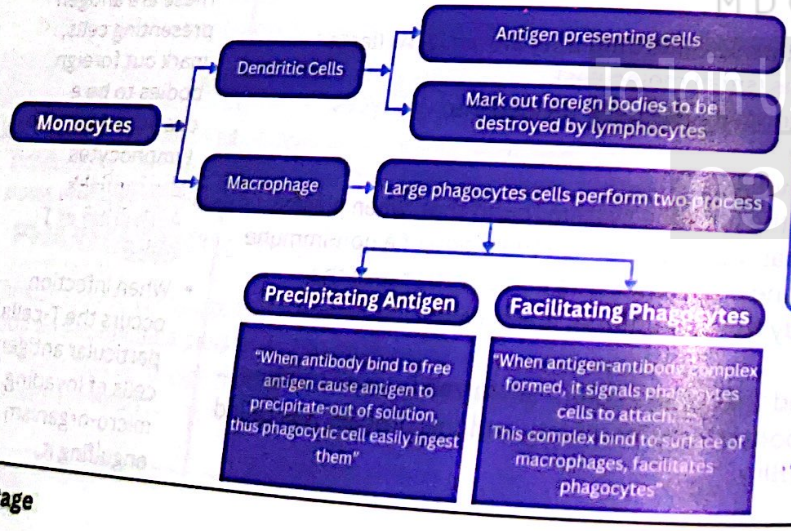
- It was also known that immunity results from the activities of lymphocytes called **B and T cells.**
- B cells give rise to cells that produce proteins called **antibodies,** which are found in the plasma.
- Because antibodies are responsible, humoral immunity is now called antibody mediated immunity.






## MONOCYTES

- From bone marrow or lymphoid tissues monocytes are transferred **(10 to 20 hours transit time)** through the capillary into tissues.
- Once in the tissue they swell and attain a larger size to become tissue macrophages and, in this form, they can live for months or even for years unless they are destroyed by performing phagocytic function.
- Macrophages secrete about 100 different compounds including interferons and enzymes that destroy bacteria.
- When macrophages are stimulated by bacteria, they secrete interleukins, which activate B cell and helper T cells.
- **Interleukins** also promote a general response to injury, causing fever and activating other mechanisms that defend the body against invasion.



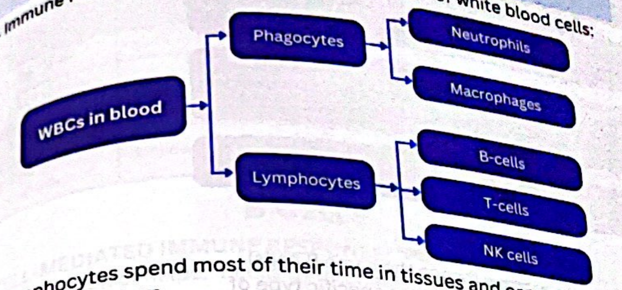

- The T-Cells display these antigens on their surface ice with the help of their own protein known as **Major Histocompatibility Complex (MHC).**
- In this way, Macrophages become **antigen presenting cells (APCs).**
- At the same time macrophages release **interleukin 1** that stimulates helper T-Cells and attracts them towards displayed antigen.
- The helper T-Cells have receptor by which they bind with specific antigen present on APC.
- The receptor on surface of T-Cells is called **T-cell receptor (TCR).**
- The T cells also stimulated by interleukin to secrete another protein called **interleukin 2** which is not only responsible for division of helper cells but also proliferates certain cytotoxic T-cells and B cells.
- There are millions of different T-cells, as each type of T-cells respond to a specific type of antigen.



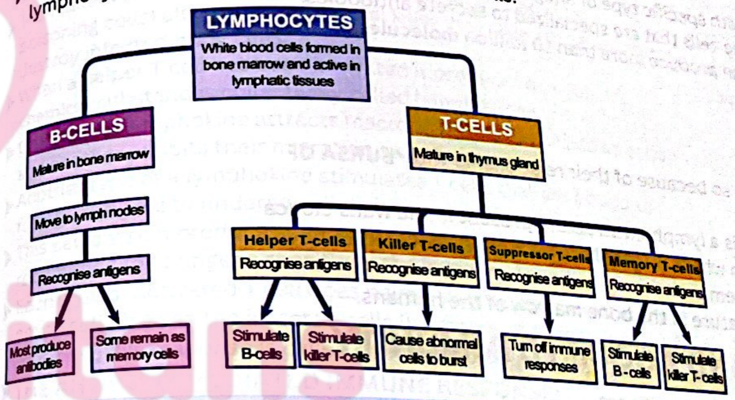
MASTER BOOK BIOLOGY ( 2ND EDITION)

## T CELLS AND B CELLS

- Immune responses depend on two main groups of white blood cells:

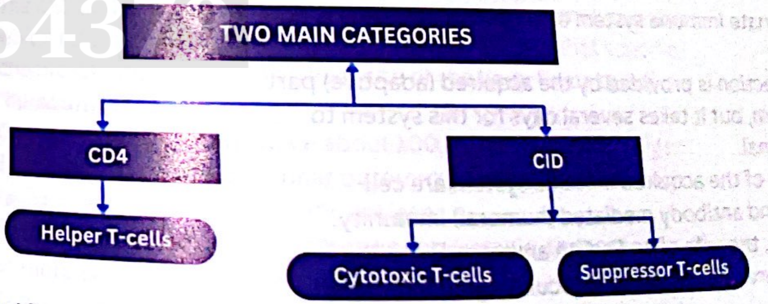



- Lymphocytes spend most of their time in tissues and organs of lymphatic system.
- Three main types of lymphocytes are: T lymphocytes or T cells, B lymphocytes or B cells and natural killer (NK) cells.

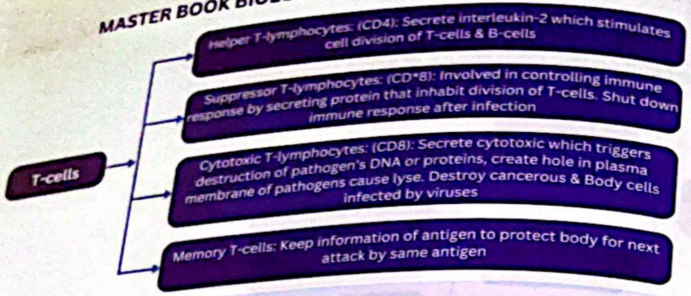



## T CELLS ARE RESPONSIBLE FOR CELLULAR IMMUNITY

- T cells originate from stem cells in the bone marrow. After early embryonic development, the newly forming T cells migrate to thymus gland for processing. (The 'T' in cells stands for thymus derived).
- The thymus makes T cells immune competent that is capable of immunological response.
- **Two main categories of T cells** have been identified.




- After activation, T-cells divide and produce four type of cells:




## B CELLS

- *B cells are differentiated in bone marrow (hence the name B cells)*
- *Each B cells carries receptors needed to bind with a specific type of antigen.*
- *After binding with specific type of antigen the B cells develop into plasma cells, the cells that are specialized to secrete antibodies.*
- *A plasma cell can produce more than **10 million molecules of antibody per hour.***

**PTB**

- *B-cells are named so because of their relationship with **'BURSA OF FABRICIUS'**.*
- *Bursa of Fabricius is a lymphoid structure present in the walls cloaca of young birds from where B-Lymphocytes were discovered to have a role in immune system.*
- *However, B- cells mature in the bone marrow of the humans.*

## INBORN AND ACQUIRED IMMUNITY

- *The two basic types of immunity are*
  - *a. Inborn or innate immunity*
  - *b. Acquired immunity*
- *If microorganisms breach the **first line** of defence i.e. skin and mucous membrane then the innate part of the immune system is available to destroy the invaders.*
- *Because the components of the innate or inborn immunity are fully active, they can function immediately upon entry of the microorganisms*
- *The ability of the innate immune system to kill microorganisms is not specific.*
- *Highly specific protection is provided by the acquired (adaptive) part of the immune system, but it takes several days for this system to become fully functional.*
- *The **two components** of the acquired immune system are cell-mediated immunity and antibody mediated (humoral) immunity.*
- *In **1717 Mary Montagu**, the wife of an English ambassador to the Ottoman Empire, observed local women inoculating their children against smallpox.*





- Edward Jenner observed and studied Miss Sarah a milkmaid who had previously caught cowpox and was found to be immune to smallpox.

| Features | Inborn/Innate Immunity | Acquired/Adaptive Immunity |
|---|---|---|
| Response Time | Hours | Days |
| Specificity | Limited and fixed | Highly diverse, improves during the course of the immune response |
| Response to Repeated Infection | Identical to primary response | Much more rapid than the primary response |

## B CELLS

### CELL-MEDIATED IMMUNE RESPONSE:

- The activation of helper T cells by **interleukin-1** and the binding of antigen to these activated helper T cells unleash a chain of events known as the **cell-mediated immune response.**
- The main event of this response is that **cytotoxic T cells** (cell poisoning cells) also known as natural killer (NK) cells, recognize and destroy infected body cells.
- When a helper T cell has been activated it produces a variety of chemical substances collectively called **lymphokines.**
- One type of lymphokine attracts macrophages to the site of infection and another inhibits their migration away from it.
- Another type of a lymphokine stimulates T cells that are bound to foreign antigens to undergo cell division many times.
- This cell division produces enormous quantities of T cells capable of recognizing the antigens specific to the invader.
- Each type of activated T cell does have a specific job. Because the entire cell binds to the infected cells (by means of specific cell-surface proteins), this response is called **cell-mediated.**

### THE ANTIBODY MEDIATED IMMUNE RESPONSE:

- When helper T cells are stimulated to respond to foreign antigens they activate the cell-mediated immune response and activate a second, more long range defence called the **antibody mediated immune response.**
- Depending upon the types of antigens present, the helper T cells may stimulate either or both of the immune response.
- The key players in antibody-mediated immunity are the lymphocytes called **B cells or B-lymphocytes.**
- The antibody response is sometimes called the **humoral response,** which refers to the fact that B cells secrete antigen that specific chemicals into the blood stream one of the body fluids called **"humours"** long ago
- On their surface B cells have about **100,000 copies** of a antigens.
- Because different B cells bear different protein receptors, each recognizes a different, specific antigen.
- At the onset of a bacterial infection for example, the receptors of one or more B cells bind to bacterial antigens.
- The B cells may bind to either free bacteria or bacterial antigens

- displayed by macrophages.
- These antigen-bound B cells are detected by helper T cells, which then bind to the antigen B cell complex after binding, the helper T cells release lymphokines that trigger cell division in the B cells.
- After about **5 days** and numerous cell divisions, a large clone of cells is produced from each B cell that was stimulated to divide
- Then the B cells begin producing and secreting copies of the receptor proteins that respond to the antigen.
- These receptor proteins are called **antibodies or immunoglobulins.**
- The secreting B cells are called **plasma cells.**
- After B cells become plasma cells they live only for a few days but secrete a great deal of antibody during the time.
- Antibodies do not destroy a virus or bacterium directly, but rather it destructs them by the mechanism of complement or macrophages.

| Antibody-Mediated Immunity (B cells) | Cell-Mediated Immunity (T cells) |
|---|---|
| 1. Host defence against infection (opsonize bacteria, neutralize toxins and viruses) | 1. Host defence against infection (especially M tuberculosis, viruses and fungi) |
| 2. Allergy, e.g., hay fever | 3. Allergy, e.g., poison oak |
| 3. Autoimmunity | 4. Graft and tumor rejection |
| | 5. Regulation of antibody response (help and suppression) |

## MEMORY CELLS

- *A person who overcomes a disease often remains immune to future encounter with that specific disease for many years.*
- *Retaining immunity is the function of memory cells. Plasma cells and cytotoxic T cells do the immediate job of fighting disease organisms, but they usually live only for a few days.*
- *B and T memory cells, on the other hand, may survive for many years. If foreign cells bearing the same antigens re-enter the body, they will be recognized by the appropriate memory cells.*
- *These memory cells will multiply rapidly, generate huge populations of plasma cells and cytotoxic T cells, and produce a second immune response.*
- *In the first encounter with a disease microbe, only a few B and T cells respond.*
- *Each of these however leaves behind hundreds or thousands of memory cells.*
- *Further, memory cells respond to antigen much more rapidly than their progenitor B and T cells could.*
- *Therefore, the second immune response is very rapid.*

## STRUCTURAL MODEL OF AN ANTIBODY MOLECULE

- A typical antibody is a **Y-shaped molecule** in which the two arms of the Y are binding sites.
- This shape emits the antibody to combine with two antigen molecules, and allow formation of antigen-antibody complexes.
- The tail of the Y performs functions such as binding to cells or

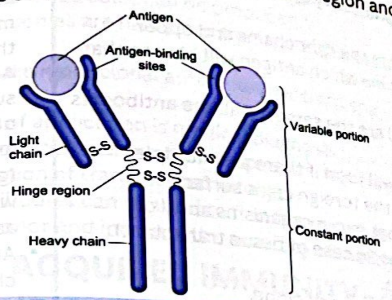






activating the complement system.

- The antibody molecule consists of **four polypeptide chains: two identical long chains** called **heavy chains,** and two identical short chains called **light chains.**
- Each chain has a **constant segment,** a functional segment, and a variable segment.
- In the constant segment, or C region, of the heavy chains, the amino acid sequence is constant within a particular immunoglobulin class.
- The C region may be thought of as the handle portion of a door key.
- Like the pattern of bumps and notches at the end of a key, the variable segment, **or V region,** has a unique amino acid sequence.
- In B-cell receptors the variable region of the immunoglobulin protrudes from the B cell, whereas the constant region anchors the molecule to the cell.

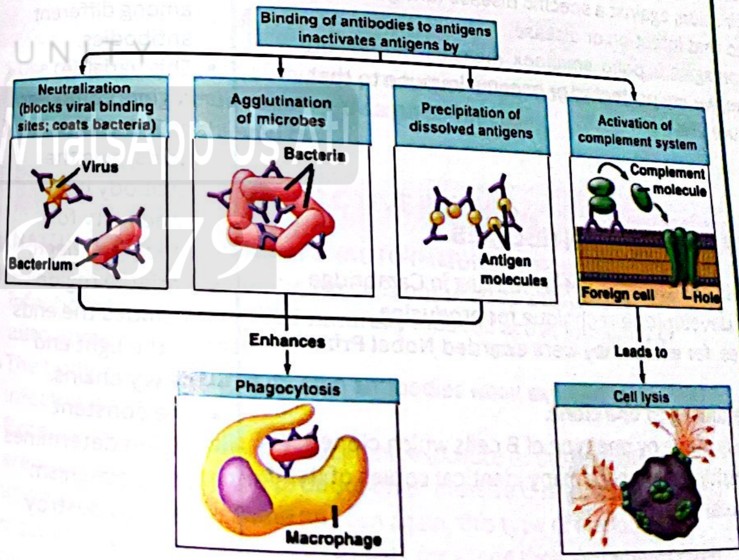



**BTB**

- The antibodies are **small glycoprotein** molecules.
- Lymphocyte is stimulated to divide repeatedly **by mitosis.**
- Large number of antibody molecules are produced in very less time (**2000 antibody molecules per second**).
- The hinge region of antibody gives the flexibility for the antibody molecule to bind around the antigen

## MODE OF ACTION OF ANTIBODIES

- Antibodies work in different ways: the antibody can bind to an antigen, forming an antigen-antibody complex thus promote phagocytosis.
- They also activate complement system. Antibodies can combine with toxins to neutralize them.




**KPK**

- All complement pathways carry out
- **6 beneficial innate** defence functions. They:
  1) Trigger inflammation
  2) Chemotactically attract phagocytes to the infection site.
  3) Promote the attachment of antigens to phagocytes (enhanced attachment or opsonization).
  4) Cause lysis of gram-negative bacteria and human cells displaying foreign epitopes.

**PTB**

- The antibodies are ***immunoglobulins*** which are synthesized by vertebrates, in response to ***antigens;*** and immobilise it, or sets in motion events that ultimately cause its destruction.
- ***Antigen or immunogen*** is a foreign substance, often a protein which stimulates the formation of antibodies
- Antibodies are ***specific*** i.e. cause the destruction of the antigen, which stimulated their production.
- Antibodies are manufactured in B-lymphocytes, then secreted in to the lymph and blood where they circulate freely.
- An antibody molecule consists of ***four polypeptide chains*** two identical light chain and two identical heavy chains-linked by disulfide (S-S-) bridges (4 bridges).
- ***Variable amino acid sequences (V)*** in the light chains and upper regions of the heavy chains ***determine*** which antigen will bind to that particular antibody.
- ***Constant amino acid sequences (C)*** are the same for all the antibodies in one class
- Large antigen-antibody complexes will form if there are multiple copies of the antigenic molecule on the foreign cell's surface.
- T-cells recognize antigen, then combat micro-organisms and / or ***effect the rejection of foreign tissues*** (in case of tissue transplant). This is called ***cell-mediated response.***
- B-cells recognize antigen and form plasma cell clone.
- These ***plasma cells synthesise*** and liberate antibodies into the blood plasma and tissue fluid.
- Here antibodies attach to the surfaces of bacteria and speed up their phagocytosis, or combine with and neutralise toxins produced by micro- organisms, by producing antitoxins. This is called ***humoral Immune response.***
- When we get vaccination, against a specific disease (antigen), we become immune to that infection or disease.
- If we get vaccination against, polio, smallpox, measles, mumps etc., once in our life time, we are protected or become immune to that infection in our future life.

**FTB**

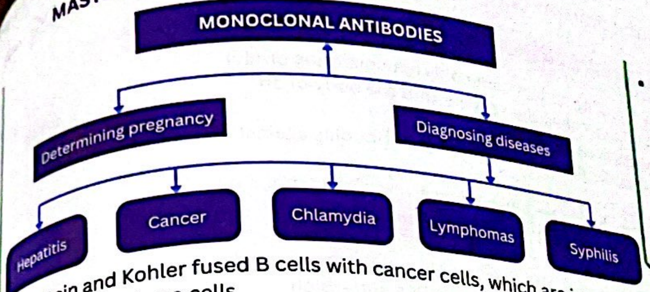
## MONOCLONAL ANTIBODIES

- In 1970, **Cesar Milstein** and **Georges Kohler** working in Cambridge solve the problem of developing a technique for producing monoclonal antibodies, for which they were awarded **Nobel Prize in 1984.**
- Monoclonal means belonging to **one clone.**
- Each type of antibody is made by one type of B cells which cloned itself in other words multiplies to make many identical copies of itself in response to a particular antigen.

**4)** Plays a role in the activation of naive B-lymphocytes.
**5)** Remove harmful immune complexes from the body.
**6)** The precursors of T cells are also produced in the bone marrow but leave the bone marrow and mature in the thymus.

- Antigens are cell surface oligosaccharides and proteins (glycoprotein) which the cell uses as **"ID tags".**
- Antibodies are chemically proteins present in blood plasma and lymph.
- The amino acid sequence in the tips of the **"Y"**, varies greatly among different antibodies.
- This variable region, composed of **110-130 amino acids,** give the antibody its specificity for binding antigen.
- Variable region includes the ends of the light and heavy chains.
- The constant region determines the mechanism used to destroy antigen.






- Milstein and Kohler fused B cells with cancer cells, which are immortal to form hybridoma cells.
- The **hybridoma cells** continue to multiply and can be cloned so that large quantities of antibodies can be produced.
- Monoclonal antibodies are harvested from cell cultures rather than animals.
- The ability to make monoclonal antibodies has been spawned a new industry.
- A common area of application is medical diagnosis.
- A monoclonal antibody has been developed which is very effective at preventing rejection of transplanted kidneys.
- Monoclonal antibodies can be used to find out the types of antigens present in the donor and increase the accuracy of matching.

- Antibodies are divided into five major classes, IgM, IgG, IgA, IgD, and IgE, **based on their constant region** structure and immune function.
- There are 5 classes of antibodies immunoglobulins

# TYPES OF ACQUIRED IMMUNITY-ACTIVE AND PASSIVE IMMUNITY

- There are two ways to acquire adaptive immunity:
  - a. Active Immunity
  - b. Passive Immunity.
- Both types may be acquired naturally or artificially. Providing immunity artificially is called **immunization.**

## ACTIVE IMMUNITY

- Use of vaccines, which stimulate production of antibodies in body, making person immune against disease or infection.
- Active immunity achieved by:

## NATURAL ACTIVE IMMUNITY

- **NATURAL ACTIVE IMMUNITY: (AUTO IMMUNE RESPONSE)**
- This is the kind of immunity, which is obtained as a result of an infection. This is also called **naturally induced active immunity or auto immune response.**
- The body manufactures its own antibodies when exposed to an infectious agent.
- Because **memory cells,** produced on exposure to the first infection, are able to stimulate the production of massive quantities of antibody when exposed to the same antigen again, this type of immunity is most effective and generally persists for a long time, sometimes even for life.

## ARTIFICIAL ACTIVE IMMUNITY (VACCINATION)

- This is achieved by injecting (or less commonly administering orally) small amounts of antigen, called the **vaccine,** into the body of an individual. The process is called **vaccination.**
- The antigen stimulates the body to manufacture antibodies against the antigen.
- But this active immunity has been achieved by artificially introducing, antigens in the body, so it is called **artificially induced active immunity.**
- Often a second, booster injection is given and this stimulates a much quicker production of antibody which is long lasting and which protects the individual from the disease for a considerable time.
- Several types of vaccine are currently in use.

## PASSIVE IMMUNITY

- In contrast to active immunity, in which antigens are introduced to stimulate the production of antibodies, by artificial or natural method; **antibodies are injected in the form of antisera,** to make a person immune against a disease, this is called passive immunity.
- In passive immunity antibodies from one individual are passed into another individual.
- **Antiserum is a serum containing antibodies**
- In body, antigen - antibody complexes are formed which are taken up by phagocytes and destroyed.
- The patient is spared the complications (or possibly death) caused by the **infection or venom.**
- They give immediate protection, unlike active immunity, which takes a few days or weeks to build up.
- Passive immunity response is **immediate, but not long lasting,** it only provides protection against infection for a few weeks, for the antibodies are broken down by the body's natural processes, so their number slowly fall and protection is lost.

## NATURAL PASSIVE IMMUNITY

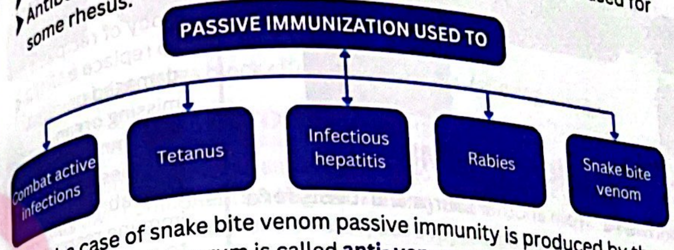
- Passive immunity may be gained naturally.
- For example, antibodies from a mother can cross the placenta and enter her foetus.
- In this way they provide protection for the baby until its own immune system is fully functional.
- Passive immunity may also be provided by **colostrum, the first secretion of the mammary glands.**
- The baby absorbs the antibodies through its gut.
- Mother to fetus through placenta → IgG.
- Mother to child through colostrum → IgA.

## ARTIFICIAL PASSIVE IMMUNITY

- Antibodies (In form of antisera), which formed in one individual extracted & injected into blood or another individual, which may or may not be of sa



- They can be used for immediate protection if a person has been; or is likely to be, exposed to a particular disease.
- For example, specific antibodies used for combating tetanus and diphtheria used to be cultured in horses and injected into humans.
- Only antibodies of human origin are now used for humans.
- Antibodies against rabies and some snake venoms are also available.
- Antibodies against the human rhesus blood group antigen are used for some rhesus.




- In the case of snake bite venom passive immunity is produced by the antitoxins so the serum is called **anti- venom serum.**
- **AIDS (Acquired Immune Deficiency Syndrome)** is a disease caused by a virus.
- The affected persons suffer **from deficiency in their immune system** of the body, and the immune system collapses.
- Thus, the AIDS victim often succumbs to a bacterial disease or cancer that under normal circumstances, the immune system can overcome.
- There is no known cure of the disease. It can spread by blood transfusion and by **sexual contact** with the infected persons.
- **Tetanus** is caused by the infection of **bacterium Clostridium tetani.**

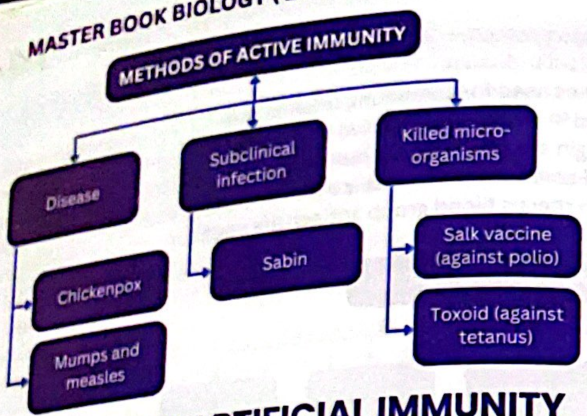
| Features | Active Immunity | Passive Immunity |
| --- | --- | --- |
| Production of Immunity | Produced because of entry of antigen | Produced because of entry of antibodies |
| Source of Antibodies | Body is stimulated to produce antibodies | Antibodies are obtained from another source |
| Substance Entering the Body | Antigen | Antiserum |
| Response | Delayed immune response | Immediate immune response |
| Duration of Protection Conferred | Prolonged | Short |
| Development of Immune Memory | Yes | No |
| Role | Preventive | Preventive and curative |

**FTB**

## ACTIVE OR NATURAL IMMUNITY

- It is a long-lasting immunity developed by antibodies produced by an
- individual's own cells.

It is developed in three ways:




## PASSIVE OR ARTIFICIAL IMMUNITY

- Passive immunity is **"borrowed"** from another source and it lasts for a short time.
- For example, antibodies in a mother's breast milk provide a baby with temporary immunity to diseases the mother has been exposed to.
- This can protect the baby against infection during the early years of childhood.
- Everyone's immune system is different.
- Some people never seem to get infections, whereas others seem to be sick all the time.
- As people get older, they usually become immune to more germs as the immune system comes into contact with more and more of them.
- That's why adults and teens tend to get fewer colds than kids their bodies have learned to recognize and immediately attack many of the viruses that cause colds.
- Every year millions of children around the globe are saved from illness or death because of vaccines.

## DISORDERS OF THE IMMUNE SYSTEM

- Disorders of the immune system are defined as those processes "That stimulate a defective immune response".

### 1) ALLERGIES

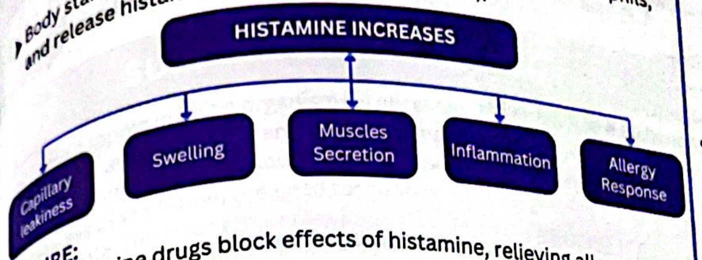
- Allergic diseases are number of disease conditions causes by hypersensitivity of the immune system to something (Allergens) in the environment that cause little or no problem to most people.
- Allergens are recognized as antigens by a particular type of B-cells.
- These B-cells proliferate, producing plasma cells that pour out Ig E antibodies attach to the plasma membrane of histamine releasing cells of respiratory and digestive tract.
- When allergen encounters the attached **Ig E antibodies**, they trigger the release of histamines which causes increased mucus secretion, leaky capillaries and other symptoms of inflammation.
- Leading to chronic health conditions like Hay fever, enzyme, asthma & food allergy.

**BTB**

- **Organ transplant** is a medical procedure an organ is removed from donor body and placed in the body of recipient to replace a damaged or missing organ.
- **Autoimmune diseases** arise from abnormal immune response to a normal body part.
- There are at least **80 types** of autoimmune disorders.
- **Common symptoms** include:
- Low grade fever
- Feeling tired Symptoms often appear and disappear
- **Transplant rejections** occur when transplanted tissue is rejected by the recipient's immune system, which destroys the transplanted tissue.
- This happens when recipient's cells recognize the donor organs and tissues as being foreign.
- **Role of T cells and B cells in Transplant**



- Body starts producing enormous quality of Ig E, bind with basophils, and release histamine (inflammatory chemicals).




- **CURE:** Antihistamine drugs block effects of histamine, relieving allergy.

### 2) AUTOIMMUNE DISEASE

- "In autoimmune diseases antibodies are going to produce against bodies own components & begin to destroy them"
- No any cure of autoimmune disease, but suppressed by drugs.
- **EXAMPLES:**
- Some types of anaemias (Antibodies destroys person's RRCs)
- Many cases of insulin-dependent (Juvenile Onset) diabetes

### 3) TRANSPLANT REJECTION

- It is often desirable that certain tissues or organs such as liver, kidney or heart is transplanted from one person o another to replace a damaged organ or tissue.
- In such cases, there is a danger that the recipient cells may recognize the donor's organs or tissues as being foreign.
- This triggers the recipient immune mechanism, which may act to destroy donor's tissues.
- Such a reaction is called **tissue rejection reaction.**

### ROLE OF T-CELLS IN TRANSPLANT REJECTION

- Although the mechanism of rejection varies with the nature of tissues and the level of incompatibility, all the mechanisms require the host T – helper cells to come in contact with the tissue's major histo-compatibility complex (MHC) antigens.
- This contact is mainly mediated by the dendritic cells of the graft tissue itself.
- At this point, three different possibilities exist:
  1. Antigen specific T-helper cells stimulate the **activation and proliferation of the appropriate T-cells** which mount a focused attack on the grafted tissue.
  2. Secondly, responsive antigen-specific **T-HELPER CELLS** move to the graft tissue, where they release **lymphokines.**
  3. They recruit monocytes/macrophages and T-cells to the graft issue and maintain them at the scene while they destroy the grafted tissue.

### ROLE OF B-LYMPHOCYTES

adaptive immune response via cellular immunity mediated by killer T-cells.

- It induces apoptosis of T-cells as well as humoral immunity mediated by activated B-cells secreting antibody molecules.
- Although the action is joined with the components of innate immune response i.e. phagocytosis and soluble immune proteins.
- However, different types of transplant tissue tend to favour different balances of rejection mechanism.

clone, producing a shower of antibodies to the implanted tissue's MHC antigens.

- These can trigger either:
  1. Complement-mediated graft damage
  2. Antibody mediated cellular cytotoxicity.
- The latter is accomplished by K or Killer-cells.

KPK

## ALLERGIES

- The most common allergic reactions includes:
  - Hay fever (allergic rhinitis)
  - Asthma
  - Allergic eyes (allergic conjunctivitis)
  - Allergic eczema
  - Hives (urticaria)
  - Allergic shocks (anaphylaxis and anaphylactic shocks)

## AUTOIMMUNE DISEASES

- **Lupus,** a chronic disease marked by muscle and joint pain and inflammation (often involves attack on kidneys and other organs)
- **Juvenile rheumatoid arthritis,** certain body parts such as joint of knee, hand and foot act as foreign tissue and body's immune system attacks them
- **Scleroderma,** a chronic autoimmune disease that can lead to inflammation and damage to skin, joints and other internal organs
- **Ankylosing spondylitis,** inflammation of spine and joints, causing stiffness and pain
- **Juvenile dermatomyositis,** a disease marked by the inflammation and damage of skin and muscles





# CHAPTER 12 SUPPORT & MOVEMENT

## SUPPORT AND MOVEMENT

- Some support in living organisms is necessary to uphold and sustain the body against gravity and other external forces.
- As the living organisms have been increased in size through the process of evolution, the need for support became greater.
- **For Example:** The strong, complex muscles of the vertebral column are adapted to provide support and movement in resistance to the effect of gravity.

## SKELETON

- Skeleton is a tough and rigid framework of the body.
- **In Unicellular Organism Skeleton:** Secreted by a single cell.
- **In Multicellular Organism Skeleton:** Consists of specialized cells.

| Feature | Exoskeleton | Endoskeleton | Hydrostatic Skeleton |
|---|---|---|---|
| Origin | Secreted by ectodermal cells | Arises from mesoderm. | Gastrovascular cavity or coelom. |
| Nature | Non-living | Living | Non-living |
| Location | Present external to skin & muscles. | Present internal to skin & muscles. | Central fluid-filled cavity. |
| Comments | Restricts movement & growth | Does not restrict movement; grows with the body. | Contraction of muscles puts pressure on the liquid, maintaining upright posture. |
| Composition | Made of chitin and CaCO3 | Made of bones & cartilage. | Made of fluid-filled cavity. |
| Joints | Simple | Complex and different types. | No joints. |
| Examples | Arthropods | Vertebrates | Cnidarians and Annelids |

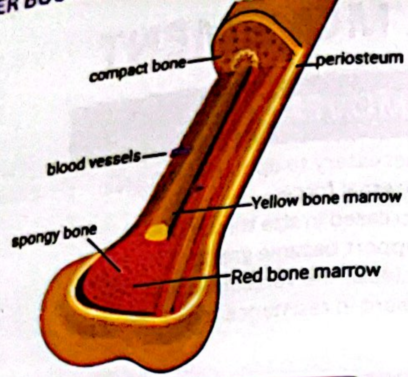
**Functions of Skeleton**

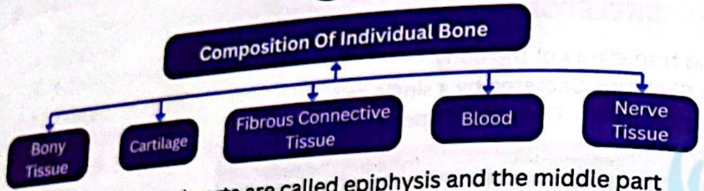
- **Support:** Provides a framework to support the body and cradle soft organs.
- **Protection:** Shields delicate organs like the heart, lungs, and brain.
- **Movement:** Bones function as levers for muscles.
- **Mineral Storage:** Stores calcium and phosphate.
- **Blood Cell Formation:** Facilitates haematopoiesis.

## HUMAN SKELETON

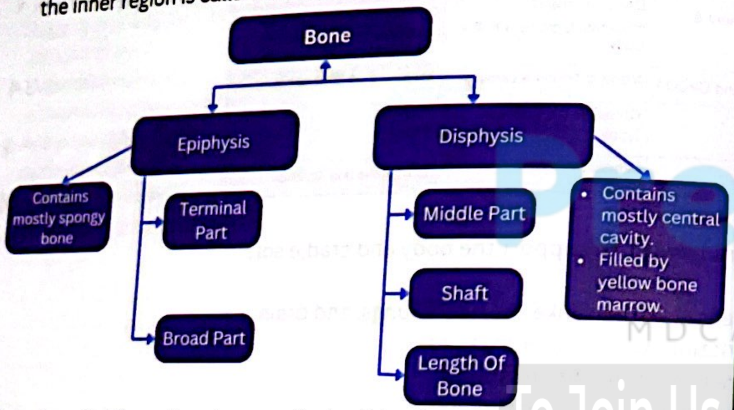
- The human skeletal system consists of **bones and cartilage.**
- The skeleton acts as a **framework that supports soft tissues.**
- It allows free movement through the action of muscles across Joints.
- The study of bones and cartilage is called **osteology.**
- **Human skeleton is about 18% of the total body weight.**
- Human endoskeleton originates from **mesoderm.**
- Both bones and cartilages are **types of rigid connective tissue.**
- Both consists of living cells embedded in the matrix of protein called collagen.

## BONES




- The terminal broad parts are called epiphysis and the middle part along the length of bone is called diaphysis or shaft which also contains a central cavity filled by yellow bone marrow.
- The outer connective tissue around the bone is called periosteum and the inner region is called endosteum.




- The terminal broad parts are called epiphysis and the middle part along the length of bone is called diaphysis or shaft which also contains a central cavity filled by yellow bone marrow. The outer connective tissue around the bone is called periosteum and the inner region is called endosteum.

## CELLS ASSOCIATED WITH BONE

- There are three types of cells associated with bone (derived from osteogenic cells) i.e.
- **Osteoblasts** are bone forming cells that synthesize and secrete unmineralized ground substances. Once the osteoblasts are surrounded by matrix, they become osteocytes.
- **Osteocytes** maintain healthy bone tissue by secreting enzymes and influencing bone mineral content. They also regulate the calcium



**BTB**

- Bone is one-third of connective tissue.
- It is impregnated with calcium salts.
- The composition of bone tissue is different from other tissues in the body.
- Bone is a hard tissue, provides support to the body, gives environment for the production of blood cells and protects internal organs of the body.

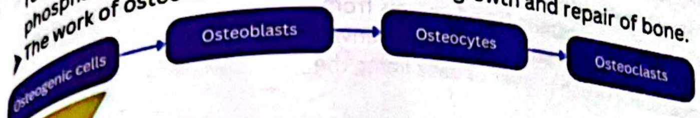
**KPK**

- Bone is a living hard (resists compression) and strong (resists bending) structure.
- It consists of a hard ground substance or matrix and cells.
- The cells are embedded in the matrix.
- The structure of bone is specially designed to withstand the compression strain falling upon it and to resist pressure.
- Bone cells engage in metabolic exchange with the blood that flows through the bones.



release from bone tissue to blood.

- Osteoclasts are the bone destroying cells. Osteoclasts perform bone resorption, i.e., they breakdown bone and deposit calcium and phosphate in the blood.
- The work of osteoclasts is important to the growth and repair of bone.




**PTB**

- The endoskeleton is primarily made up of two types of tissues, bones and cartilage.
- Both bones and cartilage are types of rigid connective tissue. Both consists of living cells embedded in the matrix of protein called collagen.

## BONE

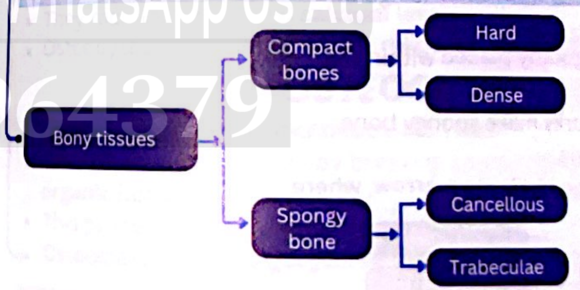
- It is the most rigid form of connective tissue.
- The collagen fibers of bone are hardened by deposit of calcium phosphate.
- Bones supporting your arms and legs consist of an outer shell of compact bone, with spongy bone in the interior.
- Compact bone is dense and strong and provides an attachment site for a muscle.
- Spongy bone is light, rich in blood vessels, and highly porous. The cavities of spongy bone contain bone marrow where blood cells are formed.

## DEVELOPMENT

- Early in development, when bone is replacing cartilage, the osteoclasts invade and dissolve the cartilage.
- Then osteoblasts replace it with bone. As bones grow, the matrix of bone is hardened, and the osteoblasts are gradually entrapped within it.

**BTB**

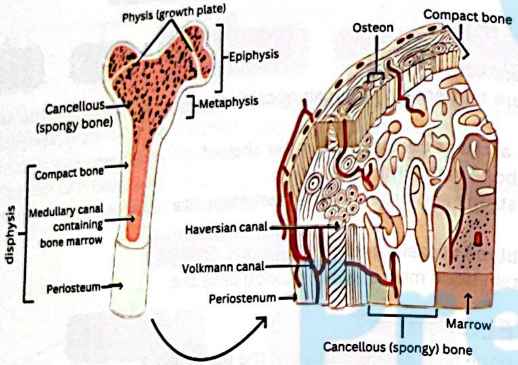
## STRUCTURE OF BONE (BTB)




## COMPACT BONE (BTB)

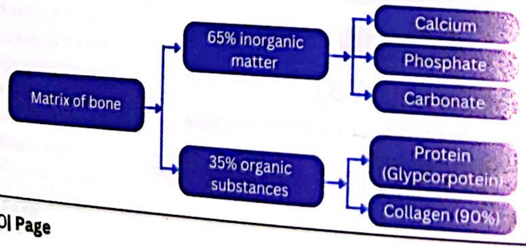
- **Compact bone**, also called **cortical bone**, is a hard white bone tissue that surrounds all the bones in the human body.
- The fundamental units of compact bone are called **osteons** or **Haversian** systems.

- Each osteon consists of concentric layers called **lamellae** (singular, lamella).
- In the centre of each osteon, **central canal** or **Haversian canal** is present which contains **blood** and **nerve supply** of the bone.
- The central canal communicates with the **perforating canal** (also called **Volkmann's canal**), which transmits blood vessels from **periosteum** (a dense layer of vascular connective tissue enveloping the bone) into the **endosteum** (The thin layer of cells lining the medullary cavity of a bone).
- The **osteocytes** are located in the small cavity called **lacunae** (singular: lacuna), situated between the lamellae.
- **Canaliculi** are the microscopic channels that create a network which transports **nutrients** to the osteocytes and also remove **wastes** from them.




## SPONGY BONE (BTB)

- **Spongy bone**, also called **cancellous** or **trabecular bone**, is a **porous** and **highly vascular** bone.
- It is mostly located at the **end of the long bones.**
- Unlike **compact bone**, the **lacunae** of spongy bone are found in a **lattice-like network** of matrix spikes called **trabeculae** (singular: **trabecula**).
- The **osteocytes** of spongy bone are **irregularly placed** within the trabeculae.
- The **spaces** between trabeculated networks make spongy bone **lighter** and **less dense** than compact bone.
- The spaces in some spongy bones contain **red bone marrow**, where the **blood cells are formed.**

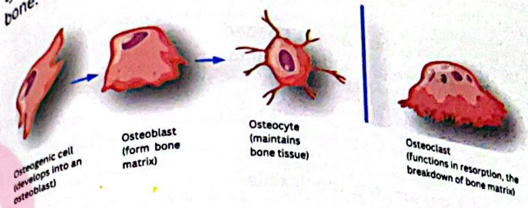







## TYPES OF BONE CELLS (BTB)

- The process of bone growth and repair is carried out by four different types of cells. These cells are involved in making and breaking the bone.




1. Osteogenic Cells are the stem cells that are found in the cellular layer of endosteum and periosteum.
2. These are undifferentiated cells and have the ability to divide. The osteogenic cells develop into osteoblasts.
3. Osteoblasts are involved in the formation of new bones.
4. They are mostly found in the areas where bone growth occurs. These cells secrete collagen.
5. Osteocytes are bone maintain cells.
6. Osteoclasts are found at the sites of old, injured bone.

- These are derived from monocytes and macrophages.

KPK

### OSTEOBLASTS

- **Osteoblasts** are **mononucleate cells.**
- They produce a **matrix** composed mainly of **Type I collagen.**
- They are responsible for the **mineralization** of this matrix.
- Osteoblasts are **immature bone cells.**

### OSTEOCYTES

- **Osteocytes** cease to generate **mineralized matrix.**
- They have many **extensions** to communicate with **osteoblasts** and other **osteocytes.**
- They maintain **bone** and **calcium** levels.
- Osteocytes regulate the bone's response to **stress** and **mechanical load.**

### OSTEOCLAST

- **Osteoclasts** are **large, multinucleated cells.**
- They remove bone tissue by breaking down its **mineralized matrix** and **organic bone.**
- This process is called **bone resorption.**
- Osteoclasts have **phagocytic-like mechanisms**, similar to **macrophages.**

KPK

### COMPOSITION OF BONE

- **Bone is a dynamic tissue** reshaped by the activity of **osteoclasts** and **osteoblasts.**

- Cells are embedded in a firm calcified matrix. 30% matrix is composed of **organic material**, mainly **collagen fibers** (90%) and **glycoproteins**.
- 70% matrix is composed of **inorganic salts**.
- The chief inorganic constituent of bone is **needle-like crystals of hydroxyapatite** (a form of **calcium phosphate**).
- **Sodium, magnesium, potassium, chloride, fluoride, bicarbonate**, and **citrate ions** are present in variable amounts.
- **Calcium and phosphate** may be released into the blood as needed, under the control of two hormones: **parathormone** and **calcitonin**.

## CARTILAGE

- It is much **softer than bone**.
- It is a form of **connective tissue**.
- It covers the **ends of bones** at the joint and supports the flexible portions of the **nose and external ears**.
- The living cells of cartilage are called **chondrocytes**.
- **Chondrocytes** secrete a tough, flexible, elastic, **non-living matrix** of **Type II collagen** that surrounds them.
- **No blood vessels** penetrate cartilage, so nutrition occurs by **diffusion**, which causes **slow healing**.

**FTB**

- **Cartilage** is not as **strong as bone** and is present at specific places only.
- It is more flexible than bone because the **matrix** is **gel-like** and contains many **collagenous** and **elastic fibers**.
- There are many small **cavities** in the matrix called **lacunae**, which contain **cartilage cells**.
- Although the **human skeleton** is initially **made up of cartilage** and **fibrous membranes**, most of these early supports are soon replaced by bones.
- A few cartilages remain in **adults**, mainly in regions where **flexible skeletal support** is needed.

**BTB**

- It is **more elastic**.
- It has no **lymphatics**. **Cartilage** has no **nerves**; it is therefore **insensitive**.
- When cartilage **calcifies**, the **chondrocytes** die, and cartilage is **replaced by bone-like tissue**.

## TYPES OF CARTILAGE

There are **three main types** of cartilage.

### HYALINE CARTILAGE

- It is the **most abundant type** in human body. It is found at the **movable joints**.
- It is found at the end of long bones and in the larynx, nose and trachea.

### ELASTIC CARTILAGE

- It has matrix containing **bundles of collagens fibers**.
- It forms **external pinnae** of ears (ear flaps) and the **epiglottis**.

### FIBROCARTILAGE

- Fibrocartilage contains wide rows of **thick collagenous fibres** is found in the disks located between the vertebrae, cartilage of knee.



## BONE VS CARTILAGE

| Bone | Cartilage |
| --- | --- |
| It is hard. | It is soft. |
| It contains osteocytes, osteoclast, and osteoblasts. | It contains cells called chondrocytes. |
| Matrix is inflexible and possesses calcium salts. | Matrix is flexible and does not possess calcium salts. |
| Rich blood supply. | No blood supplies. |
| Bone marrow is present. | Bone marrow is absent. |
| It is vascular in nature. | It is non-vascular in nature. |
| Outer covering is called periosteum. | Outer covering is called a perichondrium. |
| Provides skeletal support to the body. | Provides flexibility to the body. |
| Contains type I collagen and is densely packed. | Contains type II collagen and is loosely packed. |
| Constantly reshaped by osteoclasts and osteoblasts. | Not reshaped. |
| Deposit minerals like calcium, carbonates etc. | No mineral deposition. |

## DIVISION OF HUMAN SKELETON

Human skeletal system consists of 206 bones which are primarily divided into two divisions:

- Axial skeleton
- Appendicular skeleton

## AXIAL SKELETON

Axial skeleton includes:
i) Skull ii) Vertebral column iii) Rib cage

## I) SKULL (HEAD BONES)

- Head contains 29 bones which are divided into four divisions:

### CRANIAL BONES

- Cranial bones form cranium (brain box).
- Out of **8 cranial bones**, two are paired, i.e., **parietal bones** (left and right) and **temporal bones** (left and right), while four are unpaired like:
  - Frontal bone
  - Occipital bone
  - Ethmoid bone
  - Sphenoid bone

### FACIAL BONES

- Facial bones are **14 in number** and are attached to the cranium to form the face.
- The **six paired bones** of the face are:
  i) Lacrimal ii) Zygomatic iii) Nasal bones
  iv) Inferior nasal concha v) Maxilla vi) Palatine
- The **two unpaired bones** of the face are:
  i) Mandible ii) Vomer

### EAR OSSICLES (AUDITORY OSSICLES)

- Three pairs of middle ear ossicles are:
  i) Malleus ii) In...

## HYOID BONE

- Hyoid bone is a small single bone which lies at the base of the skull below the tongue.
- It does not articulate with any other bone of the head.

## II) VERTEBRAL COLUMN

- The vertebral column in the human body consists of **33 vertebrae.**
- Vertebral column has **4 curvatures.**
- The vertebrae may be divided into the following five groups:
  **i)** Cervical vertebrae (7) **ii)** Thoracic vertebrae (12) **iii)** Lumbar vertebrae (5) **iv)** Sacral vertebrae (5) **v)** Coccygeal vertebrae (4)

### i) Cervical Vertebrae:

- Cervical vertebrae are the vertebrae of the neck.
- The **atlas** is the first cervical vertebra.
- **Axis** is the second cervical vertebra.

### ii) Thoracic Vertebrae:

Thoracic vertebrae are rib-carrying vertebrae having large spinous processes and are found in the chest region.

### iii) Thoracic Vertebrae:

Lumbar vertebrae are present in the abdominal region.

### iv) Sacral Vertebrae (Pelvic Vertebrae):

- These are present inside the pelvic girdle.
- The anterior 5 pelvic vertebrae are sacral vertebrae, which are fused to form the **sacrum**.
- The sacrum articulates with the iliac bones of the hip bone to form the back of the pelvis.

### v) Coccygeal Vertebrae (Pelvic Vertebrae):

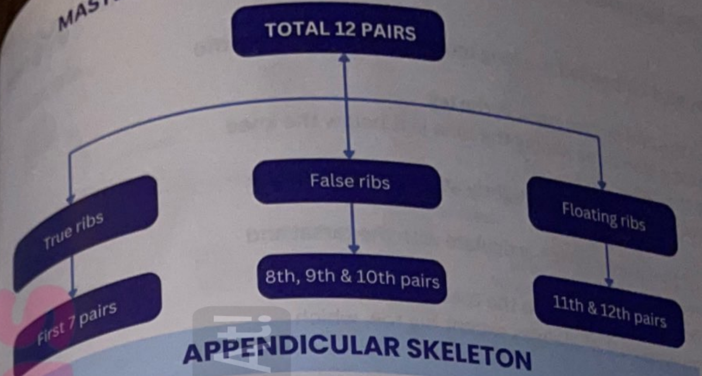
- These are present inside the pelvic girdle.
- The posterior 4 pelvic vertebrae are coccygeal vertebrae, which are fused to form the **coccyx** in adults.
- Sacral and coccygeal vertebrae are together called **pelvic vertebrae.**

## III) RIB CAGE

- The rib cage consists of **12 pairs of ribs.**
- The ribs articulate posteriorly with the thoracic vertebrae.
- Ten ribs are connected anteriorly with the sternum either directly or through the costal **cartilage**.
  - The rib cage provides support for a semi-rigid, flexible chest cavity.
  - The seven pairs of ribs that attach directly to the sternum are called **true ribs.**
  - The 8th, 9th, and 10th pairs are called **false ribs** as these three pairs of ribs are attached to the sternum by means of common costal cartilage.
  - 11th and 12th pairs of ribs are known as **floating ribs** because they do not attach to the sternum.








## APPENDICULAR SKELETON

- Appendicular skeleton includes those skeletal parts which are present in appendages (arms and legs).
- Appendicular skeleton includes:
  i) Pectoral girdle ii) Pelvic girdle iii) Forelimbs iv) Hind limbs

## I) PECTORAL GIRDLE

- Pectoral girdle consists of a pair of clavicles and a pair of scapula.
- Clavicles are a pair of collar bones.
- One end of each clavicle (curved bone) articulates with the sternum.
- The other end of clavicle articulates with the scapula.
- Scapulas are two shoulder blades.

## II) FORELIMBS (UPPER LIMB)

- Forelimb consists of humerus, radius, ulna, carpals, metacarpals and phalanges.
- Humerus is a long bone, the end of which has a spherical head, which fits into the glenoid cavity.
- Radius is a long, outer bone of the forearm (on the thumb side).
- Ulna is a long bone on the inner side of the forearm, and slightly bigger than radius.
- Carpals consist of two rows of eight short bones forming the wrist. The upper row articulates with the radius and forms the wrist joint.
- Metacarpals consist of five bones making up the palm of the hand.
- Each finger possesses three phalanges except the thumb which comprises two phalanges.

## III) PELVIC GIRDLE

- The pelvic girdle is made up of three fused bones, the ilium, ischium and pubis which form to coxal bones (coxa).
- The two halves of the pelvic girdle are joined at the pubic symphysis.
- A cavity called acetabulum is also present.

## IV) HIND LIMBS (LOWER LIMB)

- Hind limb consists of femur, patella, tibia, fibula, tarsal, metatarsal and phalanges.

acetabulum.

- Patella or the kneecap is embedded in a long tendon which runs over the knee joint.
- Tibia or shin bone is the 2nd largest bone in the leg.
- Fibula or outer bone is a thin bone joining the tibia just below the knee joint and just above the ankle.
- Tarsal is made of seven bones which are tightly attached to form the ankle.
- Metatarsal consists of five bones which articulate with the tarsal and phalanges to form the sole of the foot.
- Phalanges are small bones which make up the toes.
- Each toe of the foot possesses 3 phalanges except big toe, which comprises of 2 phalanges.

## JOINTS

- Joints occur where bones meet.
- They not only hold our skeleton together, but also give it the mobility or motility.
- They are also called articulations.
- The study of joints is called arthrology.
- It is a point of attachment between two bones or bone and cartilage.
- There are more joints in a child than in an adult because some of the bones fuse together as the growth proceeds.

There are 360 joints in the adult human skeleton.

## TYPES OF JOINTS

- Joints are classified on the basis of the amount of movement allowed by them, into three categories
- Structural classification of joints is based on the material binding the bone together and whether or not a joint cavity is present.

Types of Joints
- Immoveable Joints → Fibrous Joints
- Slightly Moveable Joints → Cartilaginous Joints
- Freely Moveable Joints → Synovial Joints

## FIBROUS JOINTS

- When the adjacent bones are directly connected to each other by fibrous connective tissue consisting mainly of collagen, it is called fibrous joint.
- In this joint the bones do not have a joint cavity between them.
- The gap between the bones may be narrow or wide.

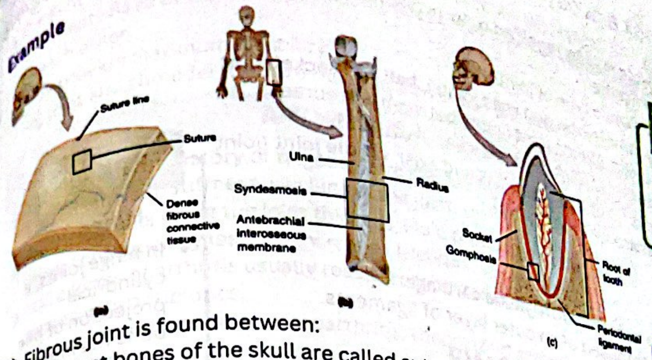
**KPK**

- In fibrous joints, a thin layer of fibrous connective tissue (a dense connective tissue mainly consisting of collagen) holds the bones firmly in position. There is no joint cavity between the bones.
- These joints provide strength and support for the body and have a protective role for the delicate structures.
- Fibrous joints are formed between sacrum and iliac of pelvic girdles, and between the bones of pelvic girdle.
- It is also present between long bones like tibia and fibula





*Example*



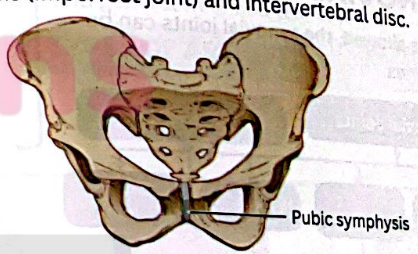

(a) (b) (c)

- Fibrous joint is found between:
  (a) Most bones of the skull are called suture.
  (b) The shaft regions of the long bones in the forearm and in the leg.
  (c) The root of a tooth and the socket in the maxilla or mandible (jawbones).

## CARTILAGINOUS JOINTS

- At a cartilaginous joint, the adjacent bones are united by cartilage, a tough but flexible type of connective tissue.
- These types of joints lack a joint cavity and involve bones that are joined together by either hyaline cartilage or fibrocartilage.
- Cartilaginous joints allow little movement or no movement.

**Example**
(a) Costal cartilage that attach ribs to the sternum.
(b) Pubic symphysis (imperfect joint) and intervertebral disc.




**PTB**

- Hyaline cartilage forms joint between growing bone.
- The bones held together by fibrous cartilage are found between vertebrae at the point where coxal bones meet in front of the pelvis.

## SYNOVIAL JOINTS

- These joints contain a cavity filled with fluid and are adapted to reduce friction between the moving joints and lubricates the articular surfaces.
- The joint is surrounded by a layer of dense connective tissue called "fibrous capsule" and their inner layer the synovial membrane which secretes synovial fluid.

**KPK**

- Bones can glide over each other to a limited extent.
- Cartilaginous joints are between wr st and ankle bones.

**BTB**

- When the articular surface of the bones is connected by cartilage (fibrocartilage or hyaline cartilage), it is called cartilaginous joint.
- Hyaline cartilage is seen in the costal cartilages that attach ribs to the sternum, fibrocartilage is seen in intervertebral disc and pubic symphysis.

**KPK**

- Synovial joints are reinforced and strengthened by a number of bandlike ligaments. These ligaments hold the bones in position.
- Based on the shape of their articular surfaces, the synovial joints have different structural plans. This structural plan determines the type of movement allowed.

- Some parts of capsule may be modified to form distinct ligament, holding the bones together.
- These are the most mobile type of joints.
- Examples are **hinge joint** (elbow and knee joints), **ball and socket joint** (hip and shoulder joints), **gliding joint** (joints between vertebrae), **ellipsoid joint or condyloid joint** (joint between skull and 1st vertebrae), **pivot joint** (joint between atlas and axis), **saddle joint** (joint between carpometacarpal of the thumb).

**FTB**

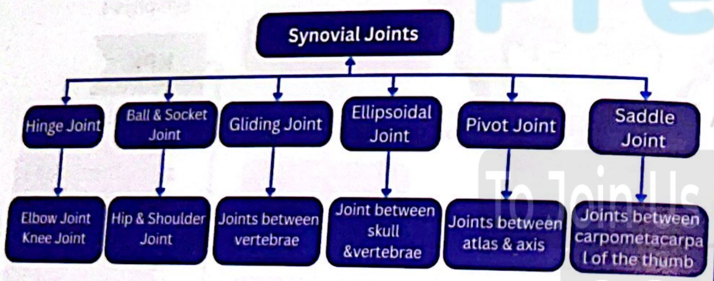
- The ends of bone are covered with hyaline cartilage.
- The joint capsule is composed of an outer layer of ligaments.

## DO YOU KNOW?

- Many joints of the body can be replaced by artificial joints. Joint replacement is called arthroplasty.
- Artificial joints are usually composed of metal, such as stainless steel, titanium alloys, in combination of modern plastics, such as high-density polythene, silastic or elastomer.
- The bone of the articular area is removed on one side. This procedure called partial joint replacement or hemi-replacement technique.
- When both sides of the articular area are removed it is called total joint replacement technique.
- The artificial articular areas are glued to the bone with a synthetic adhesive, such as methyl methacrylate.

## TYPES OF SYNOVIAL JOINTS

Based on structure and movements allowed, the synovial joints can be classified further into major categories.




## HINGE JOINT

- The joint that allows the movements in two directions (one plane).
- These are at elbow and knee.
- At these joints, pair of muscles are arranged in the same plane as that of joints.

One end of each muscle, the origin is fixed to the immovable bone on one side of joint and the other end of muscles, the insertion is attached to the far side of the joint.

## BALL AND SOCKET JOINT

**KPK**

**Hinge Joint**

- In hinge joints, a cylindrical projection of one bone fits into a trough- shaped surface on another.
- These joints permit movement in one plane, that is, permit flexion and extension only. Hinge joints can bear heavy loads.

**Ball and Socket joints**

- In ball-and-socket joints the spherical or hemispherical head of one bone articulates with the cuplike socket of another.

These joints are the most freely moving synovial joints.

**BTB**

- An infection or injury to the joints, abnormal metabolism and immune system dysfunction are the possible causes of arthritis.
- Sometimes it may be caused by inheritance as in the case of osteoarthritis.







- The joint that allows the movement in several directions (all planes).
- Such joints have at least two pairs of muscles present perpendicular to each other.
- They provide maximum flexibility.
- Hip joint and shoulder joint are the examples of ball and socket joints.

## ARTHRISTIS

- Arthritis is inflammatory or degenerative disease that damages joints.
- It results in pain, stiffness, swelling of the joint.
- The membrane, lining the joint thickens, Fluid production is decreased, which consequently leads to increased friction.
- Acute forms of arthritis usually result from bacterial invasion and are treated with antibiotics.
- Chronic arthritis includes osteoarthritis, rheumatoid arthritis, and gouty arthritis.

**FTB**

- It results in creaking sounds in the joint, difficulty in getting up from a chair and pain on walking up and down stairs.

**KPK**

**Osteoarthritis**

- It can affect joints in any part of the body.
- It is the leading cause of disability in those over the age of 65.

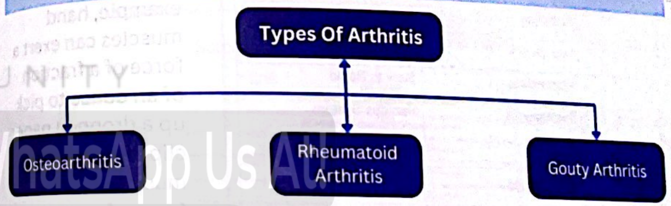
## SYMPTOMS

- The feeling of warmth around the joint.
- Redness of skin around the joint.
- Inability to move the joint easily.

## CAUSES

- Some of its causes are broken bones, infection in the area, autoimmune disease and general wear and tear of joints.

## TYPES OF ARTHRITIS




## OSTEOARTHRITIS

- It is a progressive disease in which the articular cartilage gradually softens and disintegrates.
- It affects the knee, hip, and intervertebral joints.
- It is the most common type of arthritis, and it causes inflammation of any joint.

## RHEUMATOID ARTHRITIS

- It is the result of an autoimmune disorder in which synovial membrane becomes inflamed due to faulty immune system.
- It is the inflammation of hand and wrist joints.

- It can cause joint dislocation.

## GOUTY ARTHRITIS

- It develops in those people who have high levels of uric acid in their blood.
- It is caused by the deposition of needle like crystals of uric acid in a joint (sodium urate crystals)
- It results from a metabolic disorder.
- The most common joint affected is the joint of big toe.

## MUSCLES

- The specialized tissues that can undergo contraction and relaxation and provide movements of body parts or whole body are called muscles.
- The study of muscles is called myology
- They also function to hold body parts in postural positions, movement of body fluids and heat production.
- They originate from mesoderm.
- Contain special protein filament actin & myosin.
- Invertebrates possess only smooth muscles while Vertebrate possess three kinds of muscles.

## TYPES OF MUSCLES

- There are three types of muscle tissues:

Types Of Muscles
- Smooth (Neurogenic)
- Cardiac (Myogenic)
- Skeletal (Neurogenic)

| Property | Smooth | Cardiac | Skeletal |
|---|---|---|---|
| Muscle Appearance | Unstriped | Irregular Stripes | Regular Stripes |
| Cell Shape | Spindle | Branched | Spindle or Cylindrical |
| No. of Nuclei | 1 per cell | One per cell | Many per cell |
| Speed of Contraction | Slow | Intermediate | Slow to Rapid |
| Contraction caused by | Spontaneous, stretch, nervous system, hormones | Spontaneous | Nervous System |
| Function | Controls movement of substances through hollow organs | Pumps Blood | Moves the skeleton |
| Voluntary Control | Usually No | Usually No | Yes |
| Fatigue Resistant | No | Yes | No |

## SMOOTH MUSCLES

- These are distributed widely throughout the body and are more variable in function than other muscle types.
- The smooth muscle cells are spindle shaped, with a single nucleus located in the middle of the cell.
- Myofilaments are not organised into sarcomeres. Consequently, smooth muscle **does not have a striated** appearance.
- Smooth muscle cells contain noncontractile intermediate fi...

**KPK**

- Muscle is a specialized tissue of mesodermal origin.
- Muscle tissue makes up nearly half the human body mass.
- The most distinguishing functional characteristic of muscles is their ability to transform chemical energy (ATP) into mechanical energy.
- Skeletal muscles can contract rapidly, but get tired easily and must rest after short periods of activity, or fatigued.
- Nevertheless, it can exert tremendous power.
- Skeletal muscles are also remarkably adaptable. For example, hand muscles can exert a force of a fraction of an ounce to pick up a dropped paper clip and the same muscles can exert a force of many pounds to pick heavy loads like a bucket full of water.
- Once most of the calcium is sequestered in the sarcoplasmic reticulum sacs, which takes only milliseconds, the binding between



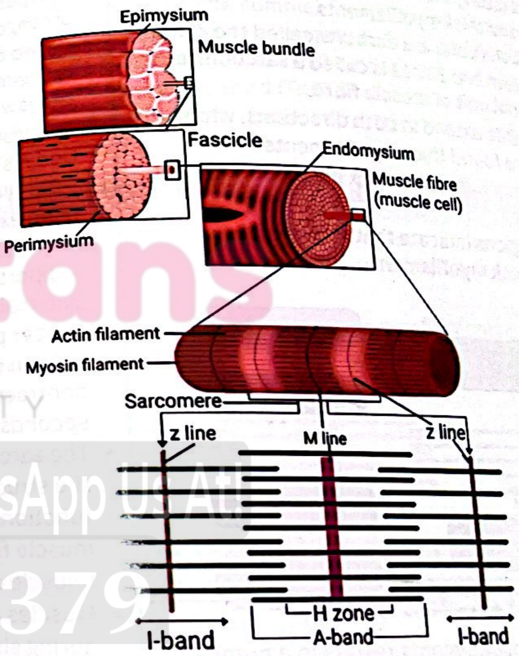
- Smooth muscles are involuntary in function.

Location Of Smooth Muscles
- Digestive
- Reproductive
- Urinary Tract
- Blood Vessels

## CARDIAC MUSCLES

- These are found only in heart.
- They branch extensively.
- Cardiac muscles are striated like skeletal muscle, but each cell usually contains one nucleus located near the centre.
- Adjacent cells join together to form branching fibres by specialised cell-to-cell attachments called intercalated discs, which have gap like junctions that allow action potentials to pass from cell to cell.
- They are fatigue resistant and troponin is present in them.

## SKELETAL MUSCLES




- These muscles are attached to the bone and are responsible for movements of body parts and whole body movements (locomotion).
- Skeletal muscles or striated muscles show alternate light and dark regions under microscope.
- Skeletal muscles are composed of muscle fibres or muscle cells.
- Bundles of muscle fibres are enclosed by collagen fibres and connective tissue.
- **At the ends of the muscle the collagen and connective tissue forms** tendons which ... skeletal elements.

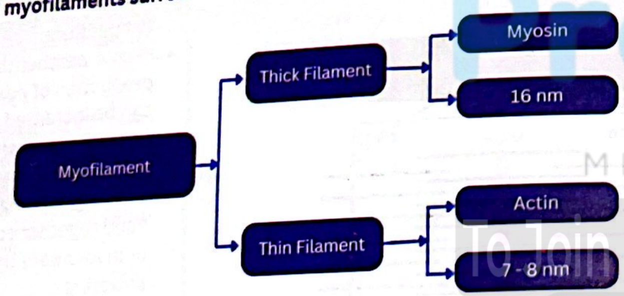
- the myosin heads and the actin filaments can no longer occur.
- The immediate source of energy for the muscle contraction is ATP, stored in the muscle cells.
- An enzyme ATPase, in the muscle cells breaks ATP to ADP, thus releasing energy for muscle contraction.
- Of the total energy expended in muscles contraction, only about 35% is utilized for the performance of work; the remaining is liberated in the form of heat, which is employed to maintain body temperature.
- In cold weather the production of heat can be increased through voluntary muscular activity (walking, rubbing hand together etc) or involuntary by shivering.
- Conversely, in warm weather, muscular activity is deliberately decreased to reduce heat production.

plasma membrane like structure called **sarcolemma** and has **several nuclei**.

- The sarcolemma of muscle fibre cell penetrates deep into the cell to form a hollow elongated tube, the transverse **tubule (T-tubule)**.
- The cytoplasm of the muscle fiber is called **sarcoplasm**.
- It contains sarcoplasmic reticulum.
- Within the muscle fibres are numerous thin myofibrils which possess characteristic cross striations. The **myofibrils are 1-2 µm in diameter** that run in parallel fashion and extend the entire length of the cell.
- Each myofibril is composed of two types of **myofilaments** thin myofilaments and thick myofilaments.

## ULTRASTRUCTURE OF SKELETAL MUSCLES

- Under a light microscope only the striated nature of the myofibrils can be observed.
- This is seen as a regular alternation of light and dark bands called the I bands and A bands respectively, transversed by thin, dark lines.
- Electron microscope studies clearly indicate that the bands are due to regular arrangement of thin and thick myofilaments.
- Transversing the middle of each I band is a dark line called the **Z line**.
- The section of myofibril between two Z lines is called a **sarcomere, which is a contractile functional unit of muscle fibre**.
- From the Z line thin myofilaments extend in both directions, whilst in the centre of the sarcomere are found thick myofilaments.
- In certain regions of the sarcomere, thin and thick myofilaments overlap.
- Transverse sections in these regions indicate that **six thin myofilaments surround each thick myofilament.**




- This arrangement of thin and thick myofilaments results in a number of other bands being recognizable in the sarcomere.
- The **entire length of thick myofilaments constitutes the A band (Dark Band)** because they are anisotropic that can **polarize visible light**.
- Thin myofilaments extend across **I band (Light Band), which is Isotropic or non-polarizing & also extend partly into A-band**.
- The centre of the A band is lighter than the outer regions in a relaxed sarcomere as there are no overlap between the thin and thick myofilament in this region. It is called the **H zone** (H stands for 'hele' means bright).
- The H zone itself may be bisected by a dark line, the **M line**.

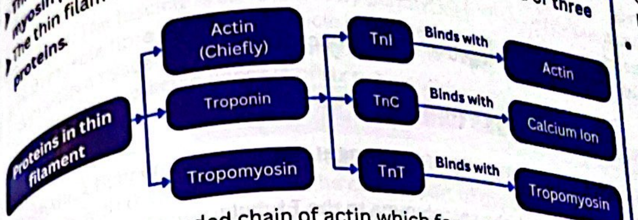
**BTB**

- There are over **640 muscles** in the body of human.
- The hardest working muscle in the body are cardiac.
- The heart pump about **2500 gallon** of blood per day.
- The smallest muscles (**stapedius**) of the body lie in the ear along with smallest bone (Stapes), while the strongest muscle, based on its weight, is the **masseter, in the jaw**.
- Longest Muscle of body is **"Gluteus maximum"**, which is main extensor muscle of hip, support the trunk and maintain proper posture.
- Human eye muscle contract in 0.01 seconds.
- The sarcomere is the structural and functional unit of muscle fibre (muscle cell
- Muscles are built during sleep, not in gym or during exercise because at this time more blood circulation and hormo- nes are released.
- Half of the myosin heads projecting from it at an angle to the left and half





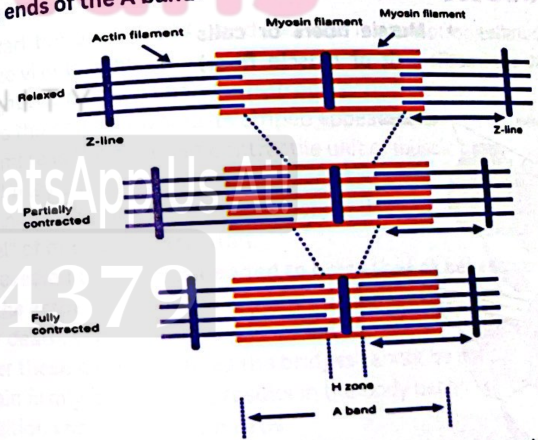
- The M line joins adjacent myosin filaments together at a point halfway along their length.
- Thick myofilaments are **16 nm** in diameter and are composed of only myosin protein.
- The thin filaments are **7-8 nm** in diameter and are composed of three proteins.




- Two intertwisted beaded chain of actin which form the core of filament.
- Two strands of tropomyosin spiral about the actin core and help stiffen it. In a relaxed muscle fibre, they block myosin binding sites on actin so that the myosin heads cannot bind to the thin filaments.
- Troponin is a three-polypeptide complex found at regular intervals on thin myofilaments. One of these polypeptides (TnI) is an inhibitory subunit that binds to actin; another (TnT) binds to tropomyosin and helps position it on actin. The third (TnC) binds calcium ions.
- Both troponin and tropomyosin help control the myosin-actin interactions involved in contraction

## MUSCLE CONTRACTION – SLIDING FILAMENT MODEL

- The sliding filament theory of contraction states that during contraction the thin myofilaments slide past the thick ones so that they overlap to a greater degree.
- In a relaxed muscle fibre, the thick and thin myofilaments overlap only **at the ends of the A band.**




- But when muscle fibres are stimulated by the nervous system, the myosin heads are attached on to myosin binding sites on actin in the thin myofilaments, and the sliding begins.
- These links are called **cross bridges** which are formed and broken several times during a contraction, acting like tiny ratchets to generate

of them angle to the right, creating an area in the middle of the filament known as **bare zone**.

- Each actin filament also contains **40-60 molecules** of tropomyosin, the protein which block the active sites of thin filaments when the muscle is relaxed.
- According to sliding filament theory of muscle contraction, the actual length of actin and myosin filament does not change but actin filaments slide over myosin filaments.
- The actual trick is played by myosin filaments.
- The sliding filament theory or model is universally accepted.

tension and propel the thin myofilaments toward the centre of the sarcomere.

- As this event occurs simultaneously in sarcomeres throughout the cell, the muscle cell shortens.
- The I bands shorten.
- The distance between successive Z discs is reduced
- The H zone disappears
- The contiguous A bands move closer together but do not change in length.

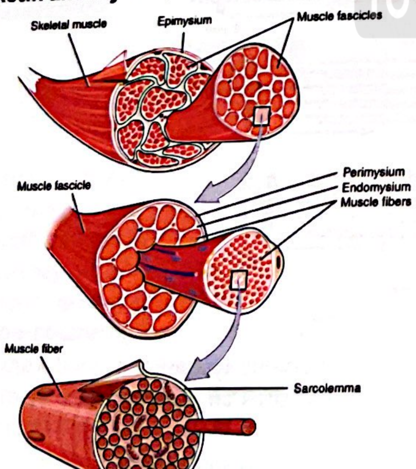
## CONTROL OF CROSS BRIDGES

- Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction.
- The nerve impulse is carried through the sarcolemma to the T tubule then to the sarcoplasmic reticulum (SR).
- The calcium gates of the SR open releasing calcium into the cytosol.
- When muscle is at rest the tropomyosin is disposed in such a way that it covers the sites on the actin chain where the heads of myosin become attach.
- When **calcium ions bind with the troponin molecules** they cause them to move slightly. This has the effect of displacing the tropomyosin and exposing the binding sites for the myosin head.
- Once the myosin head has become attached to the actin filament, ATP is hydrolysed and the crossed bridges are broken down.
- The formation and breakdown of cross bridges occur again and again during this process.

**FTB**

## STRUCTURAL SCHEME OF SKELETON MUSCLES

**Skeletal muscles → Muscle bundles → Muscle fibers or cells → Myofibrils Sarcomore (Smallest contractile unit of muscle fiber) → Myofilament (Actin and Myosin)**






- Externally muscle is covered in a connective tissue wrapping called **epimysium.**
- Each skeletal muscle consists of hundreds to thousands of muscles fibres (muscle cells).
- Each muscle is divided into discrete bundles of muscle cells called fascicles. The fascicle is surrounded by **perimysium.**
- Each muscle fibre within the fascicle is covered by a layer of connective tissue called the **endomysium**
- Each myosin molecule consists of **six polypeptides** which are arranged in such a way that each myosin molecule possesses a **tail and two globular heads.**
- Each thick filament contains about **300 myosin molecules** bundled together with their tails forming the central part of the thick filament and their heads facing outward and in opposite directions at each end.
- The kidney-shaped polypeptide subunits of actin, called globular actin or **G actin**, bear the active sites to which the myosin heads attach during contraction.
- G actin monomers are polymerized into long actin filaments called fibrous, or **F actin.**
- The backbone of each thin filament appears to be formed by two intertwined actin filaments that look like a twisted double strand of pearls.

**PTB**

- Each muscle fibre is a long cylindrical cell with **multiple oval nuclei arranged just beneath its sarcolemma.**
- Skeletal muscle fibres are huge cells. Their diameter is **10-100 μm.**
- Sarcoplasm of the muscle fibre is similar to the cytoplasm of other cells but it contains usually large amount of stored glycogen and unique oxygen bonding protein myoglobin, a red pigment that stores oxygen.
- Each dark band is called A band, because it is anisotropic, i.e it can polarize visible light.
- The light band called I band is isotropic or non-polarizing.
- It gives the cell as a whole its striped appearance.
- Sarcomere is the smallest contractile unit of muscle fibre.
- A. F. Huxley and their colleagues suggested a hypothesis in **1954** to explain all events in muscle contraction, this is called "Sliding filament model" of muscle contraction.
- It is revealed that **ATP is needed to break the link between the myosin and the actin.**
- After death, the amount of ATP in the body falls.
- Under these circumstances the bridges cannot be broken and so they remain firmly bound. This results in the body becoming stiff, a condition known as **rigor mortis.**
- Muscle contraction is initiated by nerve impulse arriving at the neuromuscular junction. **All the fibres innervated by a single motor** neuron are a "motor unit" and contract simultaneously in response to the action potential fired by the motor neurons.
- The thousands of T-tubules of each muscle cell are collectively called

T-system. It extends and encircles the myofibril at the level of Z-line or A and I junction.

- The T-tubule and the terminal portion of the adjacent envelope of sarcoplasmic reticulum form **triads** at regular intervals along the length of the fibril.
- The nerve impulse is carried through the T-tubule to the adjacent sarcoplasmic reticulum (SR).
- The calcium gates of the SR open releasing calcium into the cytosol, thus binding calcium ion to troponin molecules of the thin filament. The binding sites are exposed and cross bridges with myosin can form, and contraction occurs.

## ALL OR NONE RESPONSE

- The contraction of each muscle fibre is based on "all or none" principle i.e. all of its fibrils participate in contraction. The degree of contraction depends upon the **number of muscle fibers** that participate in contraction.
- **Sarcoplasmic Reticulum** (S.R) is continuous system of sarco-tubules extending throughout the sarcoplasm around each myofibril. It is like endoplasmic reticulum but **devoid of ribosomes** and exhibits a highly specialized repeating pattern.

## ENERGY FOR MUSCLE CONTRACTION

- Energy for muscle contraction comes from the ATP.
- Supply of ATP is maintained by the aerobic breakdown of glucose in muscle cell, which comes from stored glycogen in the cell.
- When more energy is required due to high metabolism, it is provided by another energy storing substance called **creatine phosphate**.
- Sometime during oxygen deficiency or very high metabolic activity such as prolonged or strenuous exercise ATP requirement is met by anaerobic breakdown ofglucose into lactic acid.
- Lactic acid accumulation causes muscle fatigue.
- At rest, 1/5 of the lactic acid is broken aerobically and its energy is used to change the remaining 4/5 lactic acid into glucose.

# EFFECT OF EXERCISE ON MUSCLE ACTIVITY

- The amount of work a muscle does is reflected in muscular activity.
- When muscles are used actively, they increase on size and become more efficient and fatigue resistant.
- Aerobic exercises such as swimming, jogging, and fast walking result in several changes in skeletal
- Capillaries surrounding the muscle fibres , as well as mitochondria within them increase in number and fibre synthesizes more myoglobin.
- These changes result in more efficient muscle metabolism and fatigue resistant.
- Complete immobilization of muscle leads to muscle weakness and severe **atrophy**.

# ANTAGONISTIC ARRANGEMENT OF SKELETAL MUSCLES



- There are 650 muscles in the human body, most of which occur in pairs. At joint, these muscles work against each other by contraction. This relationship is called **antagonism**.
- The skeletal muscles produce movements by pulling on tendons, cords of connective tissues that anchor muscle to the bones. The tendons then pull on bones.
- Bones are attached to the bones through connective tissue called **ligament**.
- When a muscle contracts one end normally remains stationary and the other end is drawn towards it.
- The end which remains stationary is called **origin** and that which moves is called **insertion**.
- Both are the points of attachment to bones. Every muscle has its own origin and insertion.
- **Belly** is the thick part between origin and insertion which contract.
- Normally the bone of insertion is pulled upon when muscle contracts and drawn towards origin, one bone moving on the other at the joints.
- **Flexor muscle** when contracts it bends the bone at joint.
- **Extensor muscle** when contracts it straightens the bone at joints.
- For the movement of the bone in two directions muscles work in pairs. When flexors contract the extensors relax and vice versa.
- Such an arrangement of muscles is called **antagonistic arrangement**.

FTB

## MOVEMENT IN KNEE JOINT

- **Knee or tibio-femoral joint** is located between the femur and tibia.
- It is a complex hinge joint that permits limited rolling and gliding movements in addition to flexion and extensions.
- The flexion is carried out by the flexor muscles.
- These are **hamstring muscles** present at the back of the upper part of the leg (thigh).
- The major hamstring muscle is **biceps femoris**.
- It has two origins, one from the pelvic girdle and the other from the top of the femur.
- At its insertion, the tendon divides into two portions to attach at the upper part of the tibia and fibula.
- The extension is carried out by the extensor muscles which are present in the front of the thigh.
- The main extensor muscles are **quadriceps femoris**.
- They originate at the ilium and femur, come together in a tendon surrounding the patella (kneecap), and insert at the tibia.
- These extend the leg at the knee joint and are important for standing, walking, and almost all activities involving the legs.

## ANTAGONISTIC ARRANGEMENT OF MUSCLES AT THE ELBOW JOINT

| Muscle | Origin | Insertion | Function |
|---|---|---|---|
| Biceps | By two heads from scapula | Medial surface of radius | Lifts radius (flexion) |
| Brachialis | Humerus | Ulna | Lifts ulna (flexion) |
| Brachioradialis | Humerus | Radius | Lifts radius (flexion) |
| Triceps | By three heads from scapula & humerus | Olecranon process of ulna | Straightens elbow (extension) |

## TENDONS VS LIGAMENTS

| Feature | Tendons | Ligaments |
|---|---|---|
| Definition | Connects skeletal muscles to bone. | Connects bone to bone. |
| Location | Connects ends of muscles to any place of bone. | Connects ends of bones to only at joints. |
| Elasticity | Tough & Inelastic | Elastic |
| Number | One tendon per muscle | Many ligaments per joint |
| Collagen Fiber | More | Less |
| Colour | White | Yellow |
| Blood Supply | More blood supply | Poor blood supply |

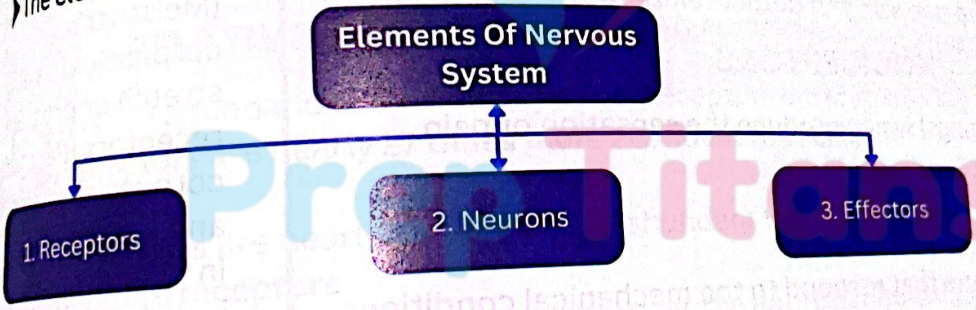
# NERVOUS COORDINATION

## INTRODUCTION

- All animals share common characteristics, including responding to stimuli (any internal or external change).
- Activities of different body parts must be coordinated in response to stimuli.
- Coordination enables the integration of functions essential to animal behaviour.
- It is essential for the survival of animals and humans.
- Humans and most animals have two types of coordination: nervous coordination and endocrine coordination.

## NERVOUS COORDINATION

- This coordination involves specialized cells or neurons connected directly or via the central nervous system, forming networks that link receptors (cells or organs receiving stimuli) with effectors (those executing responses).
- Neurons **generate and conduct impulses** across synapses, transmitting signals from receptors to effectors, thereby facilitating nervous coordination.
- The elements of nervous system which help in co-ordination are:



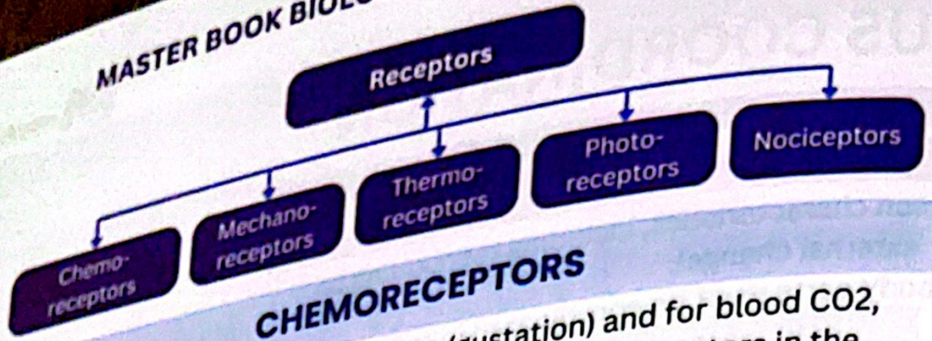



**FTB**

- The nervous system is the body's coordination system, using electric signals among different parts to respond to specific stimuli.
- The human nervous system is the most evolved of all animals.
- The study of the nervous system's structure is called **neurology.**
- In higher animals, nervous coordination involves **three basic steps:** reception of stimulus, processing/analysis of information, and response to stimulus.
- The human nervous system is the most developed, advanced, and evolved among all organisms.

## RECEPTORS

- The neuron fibers and cell bodies can be excited by small electric shocks, mechanical, chemical, light and temperature stimuli.
- Receptors detect changes in the external and internal environment of the animal.
- ...uron ending or a receptor organ.




## CHEMORECEPTORS

- These are for smell (olfaction), taste (gustation) and for blood CO2, oxygen, glucose, amino acids and fatty acids (e.g. receptors in the hypothalamus)

## MECHANORECEPTORS

- These detect stimuli of touch, pressure, position or acceleration, hearing and equilibrium (ear).
- (e.g. Free nerve endings + expanded tip endings + stray endings)

## PHOTORECEPTORS

- Electromagnetic receptors, these respond to stimuli of light, for example rods and cones in the retina of the eye.

## THERMORECEPTORS

- These are free nerve endings. These show a response to cold and warmth.
- They are mostly present in skin and detect temperature stimulus.

## NOCICEPTORS

- (Undifferentiated endings) which produce the sensation of pain.



### PTB

- There are many receptors that respond to the mechanical conditions of internal organs.
- Examples include stomach wall receptors involved in arousal of 'hunger'.
- Stretch receptors in the carotid and aortic arteries of tetrapods regulate blood pressure; similar endings are found in the branchial vessels of fishes.
- Each principal type of sensation we experience, such as pain, touch, sight, and sound, is called a **modality of sensation**.
- Although we experience different modalities of sensation, nerve fibres transmit only impulses because each nerve tract terminates at a specific point in the CNS.
- The type of sensation is determined by the termination point in the nervous system.
- For example, touch impulses are carried in the 'touch' area of the brain, while fibres from the retina terminate in the visual cortex.
- Moreover, each receptor organ is specialized to receive a particular type of stimulus and carries it to a specific area of the brain.

### BTB

- Chemoreceptors, which detect the concentration of certain chemicals or ions, e.g. $CO_2$ level in the blood by **medulla of brain**, $O_2$ level by **carotid body**.

### KPK

- Chemoreceptors in the hypothalamus, called **osmoreceptors**, detect changes in blood osmotic pressure.
- Mechanoreceptors include touch receptors (Meissner's corpuscles in skin), stretch or pressure receptors (Pacinian corpuscles in skin and baroreceptors in blood vessel walls).
- Pain receptors are the most numerous skin receptors. Every **square centimeter of skin** contains around **200** pain receptors, but only **15** pressure receptors, **6** cold receptors, and **1** warmth receptor.

# WORKING OF SENSORY RECEPTORS WITH SPECIAL REFERENCE TO SKIN

- In the skin there are at least **3 different types of sensory endings** involved in touch stimulus reception.
- In skin, the receptors are concerned with at least five different senses: touch, pressure, heat, cold and pain.

1. Situated at the base of hairs, **hair end organs** receive **touch stimulus.**

## MEISSNER'S CORPUSCLES

2. **(Encapsulated endings)** which lie in papillae which extend into the ridges of the fingertips.

- The corpuscle consists of spiral and much twisted endings, each of which ends in a knob. These are **touch receptors.**

## PACINIAN CORPUSCLES

- They receive **deep pressure stimulus**. Those located in the limbs probably form a basis for vibration sense.
- The detection of vibrations of the ground by terrestrial vertebrates is probably achieved by **receptors in the joints**.
- The intensity of stimulus received would either be transmitted in the form of repeated impulses or by more fibres carrying the impulse to the CNS.

## RELATIVE EFFICIENCY OF RECEPTORS

- The relative abundance of various types of receptors differ greatly e.g. **pain receptors** are nearly **27 times** more abundant than **cold receptors.**
- **Cold receptors** are nearly **10 times** more abundant than **heat** or temperature **receptors**.
- The receptors are not distributed evenly over the entire surface of the body.
  e.g. touch receptors are much more numerous in the fingertips than in the skin of the back, as might be expected in view of the normal functions of those two parts of the body.



## PATHWAY OF IMPULSE

- The stimulus received by the receptors in the skin which are the endings of sensory neurons is passed to the motor neurons via inter or associative neurons which are present in the brain and via spinal cord impulse is sent by the motor neurons to the effectors, which are muscles and glands.

**Receptors** $\xrightarrow[\text{sensory neurons}]{\text{Through}}$ **Interneuron (CNS)** $\xrightarrow[\text{motor neurons}]{\text{Through}}$ **Effectors**

- The sensations of touch, pressure, heat, cold, and pain are detected by modified sensory neurons having **naked nerve endings** (touch and pain receptors) or **specialized cellular corpuscles** (pressure, hot and cold receptors).

**BTB**

**SMELL OR OLFACTORY RECEPTORS**

- In humans, smell is less developed and important than vision and hearing, while in most predators, it is highly developed and crucial for detecting prey.
- Neuron axons carry smell impulses to the forebrain's olfactory bulb for responses.
- About **1,000 different receptor** proteins on neurons are each sensitive to different odors.

**TOUCH (TACTILE RECEPTOR)**

- **Two touch receptors** (mechanoreceptors ): disc-shaped dendrite S endings called Merkel's discs and egg-shaped Meissner's corpuscles ("corpuscle" means "little body").
- Both receptors are widely distributed in the skin, most numerous in hands (fingertips), feet, eyelids, tongue tip, lips, nipples, clitoris, and penis tip.
- Additionally, free nerve endings wra around hair roots, detecting stimuli

**FTB**

Receptors act as transducers because they convert one form of energy into another form e.g., rod and cone cell in the retina of eye convert the light energy into nerve impulse (electro chemical energy).

## SENSORY RECEPTORS AND THEIR WORKING

- The body detects internal and external events via sensory receptors.
- We discuss receptors for smell, taste, touch, and pain.

### OLFACTORY RECEPTORS (SMELL)

- Olfactory receptors are chemoreceptors stimulated by chemicals dissolved in liquids.
- Olfactory organs with these receptors are in the **upper nasal cavity.**
- Olfactory receptor cells are neurons surrounded by **columnar epithelial cells with cilia** at their distal ends.
- Chemicals entering the nasal cavity as gases must partially dissolve in watery fluids around cilia to stimulate olfactory receptors.

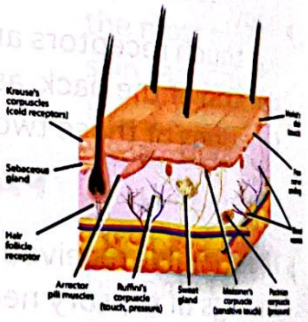
### TASTE RECEPTORS (GUSTATION)

- Taste buds are mainly on the tongue's surface, associated with tiny elevations called papillae.
- Each bud contains modified taste cells functioning as receptors and has an opening called the **taste pore**.
- Tiny projections called taste hairs protrude from outer end of taste cells through the taste pore.
- Thousands of taste buds perceive tastes through **four primary sensations:** sweet (sucrose, glucose, simple sugars), sour (acids), salty (NaCl, salts), and bitter (alkaloids, potentially toxic plant substances).
- All the four regions overlap at certain places.



## SENSORY RECEPTORS IN HUMAN SKIN

- The dermis contains receptors for touch, pressure, temperature, and pain. Meissner's corpuscles and Merkel disks are touch receptors.
- These are small, oval masses of flattened connective tissue cells. Two or more sensory nerve fibers branch into each corpuscle.
- **Meissner's corpuscles** are most numerous in the lips, fingertips, palms, and soles.
- Skin also has cold and heat receptors for temperature detection.
- **Pain receptors** are located in the epidermis to detect pain. These free nerve endings respond to chemicals from damaged tissues or excessive heat or pressure.
- These receptors are distributed throughout the skin and inner tissues, excluding the tissues the brain.




## PROCESSING/ANALYSIS OF INFORMATION

- Sensory inputs from various receptors are received by the CNS (brain and spinal cord), the body's coordinating center.
- This information is processed by associative or intermediate neurons for appropriate responses.

like wind or insects moving body hair.

### PAIN RECEPTORS (NOCICEPTORS)

- Three types of pain receptors: cutaneous (skin), somatic (joints and bones), and visceral (all organs except brain).
- These receptors are naked dendrites responding to chemicals from injured tissues or excess pressure and heat stimuli.

### THERMORECEPTORS

- Encapsulated nerve endings in the skin's dermis (Ruffini endings for heat and Krause end bulbs for cold).

# NEURONS

- The chief **structural and functional** units of the nervous system are neurons, but there are other cells, in higher animals, and in humans called **neuroglia or glial cells,** which make up as much as half of the nervous system.
- Neuroglia plays a vital role in the support, nutrition of neurons and their protection by myelin sheath.

## STRUCTURE OF TYPICAL NEURON

- The neuron has protoplasmic processes arising from its cell body containing nucleus and various organelles embedded in the cytoplasm.
- There are two main types of cytoplasmic processes or fibers.
- The one which receives stimuli & carries impulse towards cell body is called dendron, if it is a single fiber but if smaller fibers, they are called **dendrites** (singular: dendrite).
- The dendrites unlike the axon, often give a **spiny look.**
- The dendrites of certain brain cells branch profusely, giving cell a **treelike appearance.**
- The processes conducting impulses away from cell body are termed **axons.** These may be more than a meter long in some neurons.
- **Nissl's granules,** which are groups of ribosomes associated with rough E.R, and Golgi apparatus are present in the cell body.

**Cytoplasm Of Neuron**
- Microtubules
- Neurofibrils
- Rough Endoplasmic Reticulum
- Mitochondria

- The **cell body or soma** is the main nutritional part of the cell and is concerned with the biosynthesis of materials necessary for the growth and maintenance of the neuron.

If the cell body of the neuron remains intact, it can regenerate axonal and dendrite fibers; but neurons once mature, do not divide any further

**Functional Types of Neuron**
- Sensory (Afferent)
- Associative (Inter/Relay)
- Motor (Efferent)

## SENSORY NEURONS

**Receptors** $\xrightarrow{\text{Sensory Neurons}}$ **Interneuron (CNS)**

- Many sensory neurons have only one fibre, which branches a short distance from the cell body.
- Except for its terminal portions, the entire fiber is structurally and functionally of the axon type.
- A sensory neuron of this type has **no true dendrites**

**BTB**

- The cell body, also called **cyton** or **perikaryon,** contains various organelles except centrioles.
- Nissl granules assist in forming the **acetyl choline enzyme.**
- The axon's cell membrane is known as the axolemma.
- In myelinated neurons, impulses jump from node of Ranvier to **node of Ranvier,** called **saltatory impulses.**
- Sensory neurons are unipolar, having one fiber from the cell body that branches into two: one towards the receptor and one to the CNS.
- Most sensory neurons are unipolar, with some bipolar, unipolar are found especially in the spinal cord's dorsal root.
- Inter neurons are mostly multipolar because many fibers arise from the cell body.
- Motor neurons are multipolar neurons
- Their cell body contains many branched dendrites, and a single long axon runs towards effector.

- One branch (peripheral) running between the receptor site and the dorsal-root ganglion in which the cell body is located. It is called dendron because it conducts impulses towards cell body.
- The other branch (central) running from the ganglion into the spinal cord or brain. It is called axon because it conducts impulses away from cell body.

## ASSOCIATIVE NEURONS (INTER/MIXED/RELAY)

- They are neurons, which occur exclusively in spinal cord and brain.
- They serve as an intermediate link between numerous sensory and motor neurons.

## MOTOR NEURONS

Messages From CNS $\xrightarrow{\text{Motor Neurons}}$ Effectors

- Motor neurons have long axons that run from the C. nervous system to the effector (muscle); these axons are frequently, "but not always myelinated.
- Note the presence of many granules in the cell body and dendrites and their absence from the axon.

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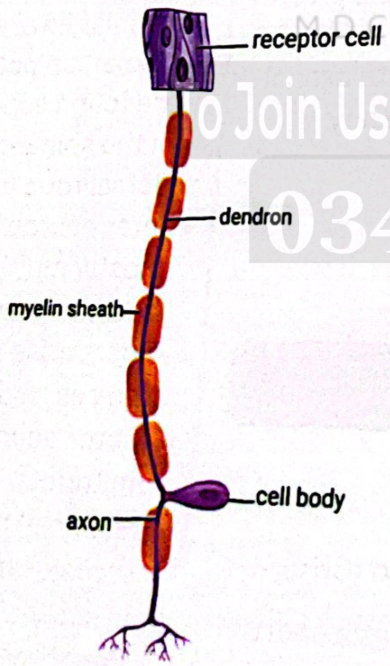
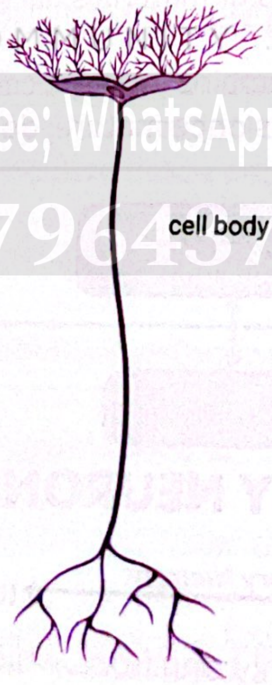
- Despite varying sizes and shapes, neurons have **three basic components:** a cell body, dendrites, and an axon.
- The cell body, or neuron cell body, contains granular cytoplasm and a cell membrane (neurilemma).
- A single large nucleus is centrally located with a prominent nucleolus.
- Golgi apparatus, mitochondria, and other organelles are present.
- The cytoplasm is characterized by Nissl's granules, groups of ribosomes and rough ER involved in protein synthesis.



sensory neuron (unipolar)



Interneuron (multipolar)



- **Dendrites** are short and thin, often highly branched cytoplasmic extensions that are gradually tapered from their bases to their tips.

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**NEUROGLIAL CELLS**

- These specialized cells are the nervous system's information-processing units, receiving and transmitting information from receptors and effectors.
- Dendrites and axons are fibrous structures.
- Dendrites increase the cell body's surface area.
- Axons have more cytoplasm (axoplasm) than dendrites.
- Some neurons have few dendritic branches, while others are highly branched to receive much information.
- Some neurons have short axons, while others can be quite long.
- The dendrite endings of some sensory neurons also act as receptors.
- Associative neurons have a highly branching dendritic network, giving the cell a tree-like appearance.

**MYELINATED AND NON-MYELINATED NEURONS**

- Myelinated neurons (nerve fibers) are

axons of other neurons form synapses with the dendrites.

- Axon is comparatively a long and thick nerve fiber which has a constant diameter and can vary in size from a few mm to more than a meter length.
- It may be branched or un- branched.
- Axons terminate by branching to form small extensions with enlarged ends called presynaptic terminals.
- Functionally, axons conduct action potentials from the neuron cell body to the presynaptic terminals, i.e., conduct signal (information) away from the cell body.
- **Schwann cells** are neuroglial cells in the peripheral nervous system.
- Usually, axons are covered by Schwann cells which are strip-like cells wrap around axon fibers.
- Schwann cells are also covered by a fatty substance called myelin sheath that acts as an insulator.
- This is why axons are called myelinated fibers.
- A non-myelinated part of axon between two Schwann cells is called **node of Ranvier**.
- A **unipolar neuron** has a single process an axon that extends from the cell body and divides into two.
- In **bipolar neurons**, the cell body is located between the two processes: an axon and a dendrite e.g., retina of the eye.
- **Multipolar neurons** have three or more processes i.e., the several dendrites and one axon.
- **Velocity of impulse** in axon fiber depends upon the diameter, length and myelin sheath.
- The larger and thicker the axon, the faster it transmits information.
- Myelinated axons transmit information much faster than other neurons.

covered by a fatty layer called the myelin sheath (axons), whereas non-myelinated neurons lack a myelin sheath (dendrites and cell bodies).

- In myelinated neurons, impulse conduction is faster than in non-myelinated neurons.
- Interneurons are non-myelinated, while motor and sensory neurons have myelinated portions.
- Nerve impulses are **20 times faster** in myelinated neurons than in non-myelinated neurons.

## TYPES OF NEURONS

- In **sensory neurons**, the cell body is at the end of a short stalk on one side of the main conducting fiber outside the CNS. The branches connect to the receptor.
- In **motor neurons**, dendrites contact other neurons in the spinal cord. Terminal branches at the neuron's far end connect to an effector.
- **Interneurons** occur entirely within the CNS.
- They convey messages between various CNS parts. The axon is comparatively thin and non-myelinated.

## EFFECTORS (RESPONSE TO STIMULUS)

- These structures respond when stimulated by impulses from motor neurons.
- The principal effectors are glands, which secrete, and muscles, which contract.
- The flow of information through the nervous system is explained by a reflex arc.

## REFLEX ARC

- A reflex arc is the pathway of an impulse during a reflex action, which is **involuntary**.

- The stimulus direction is from receptors to sensory neurons to associative (relay) neurons, then through motor neurons to effectors.
- Studying a reflex arc example clarifies the impulse flow through receptors, neurons, and effectors.
- This **simple reflex** circuit includes all **four elements** of a neural pathway.
- The **sensory neuron** has pain-sensitive endings in the skin and a long fiber leading to the spinal cord via a spinal nerve.
- The sensory neuron's cell body is outside the cord.
- The sensory neuron enters the dorsal nerve root of the spinal cord.
- The impulse crosses a synapse to an interneuron within the cord, which stimulates an association neuron.
- The **association neuron** in the spinal cord stimulates a motor neuron.
- The **motor neuron** branches to form synapses with several muscle cells **(effectors)**.
- The **motor neuron's** axon carries action potentials to muscles, causing them to contract and withdraw the body part from the damaging stimulus.
- The sensory neuron also makes a synapse on association neurons not involved in the reflex that carry signals to the brain, informing it of the danger.

**FTB**

- Reflex action is an immediate, automatic response external and internal to environmental changes.
- A typical reflex arc includes five fundamental parts: receptors, sensory neurons, interneurons, motor neuron and effectors.

## NERVE IMPULSE

- Nerve impulse is information or a signal about a stimulus transmitted from receptors to the CNS and from the CNS to effectors.
- Technically, a nerve impulse is a **wave of electrochemical changes** traveling along a neuron from one end to the other, involving chemical reactions and ion movement across the cell membrane.
- The term "electrochemical" refers to the electrical potential (capacity to do electrical work) on the neuron membrane.
- It represents a type of stored energy manifested during charge separation across a barrier.
- In neurons, the charges are positive and negative ions, and the charge-separating barrier is the plasma membrane.
- The electrical potential that exists across a cell membrane is known as membrane potential which is exhibited in **two different forms.**

1. **Resting Membrane Potential (RMP)**
2. **Active Membrane Potential (AMP)**

## RESTING MEMBRANE POTENTIAL

- Characterized by a **more positive outer surface** of the neuron membrane than the inner surface.
- This net charge difference between the inner and outer surfaces of a

**KPK**

- Reflex activities do not involve the brain; therefore, the nerve impulse pathway is slightly modified and quicker than the general pathway.
- The peripheral branch of sensory neurons transmits impulses to the dorsal root ganglion, from where impulses are carried to the spinal cord by the central branch of sensory neurons.

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- After the action potential peak **(spike potential)**, membrane permeability to $Na^+$ decreases, while it becomes more permeable to $K^+$, which rapidly diffuses from the cytoplasm to the extracellular fluid due to the opening of $K^+$ gates. Now, $Na^+$ gates are closed.
- Soon, this part of the neuron membrane regains its original polarity, becoming electropositive outside and electronegative inside. This is called **repolarization**

non-conducting neuron is called the resting membrane potential.

- Also known as the **polarized state**, the neuron is at rest.
- Indicates an unequal ion distribution on the two sides of the nerve cell membrane.
- The potential generally measures about **70 mV**, with the inside of the membrane negative relative to the outside.
- Thus, the resting membrane potential is expressed as **-70 mV or -0.07 V**, with the minus indicating the inside is negative compared to the outside.
- It is called a resting membrane potential because it occurs when a membrane is not being stimulated or conducting impulses.
- Resting membrane potential is established by the **following factors:**

## DISTRIBUTION AND ACTIVE MOVEMENT OF $NA^+$ AND $K^+$ IONS

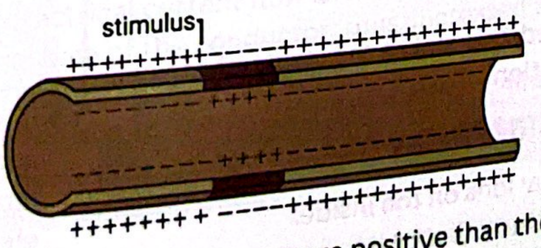
- The concentration of **potassium ($K^+$)** is **30 times greater** inside the cell than outside, while **sodium ions ($Na^+$)** are nearly **10 times greater** outside the cell than inside.
- These ions are continuously moved against their concentration gradients by sodium-potassium pumps, using energy from ATP split by the enzyme ATPase.
- For every **two $K^+$ ions** transported inward, **three $Na^+$ ions** are pumped out.
- This makes the inside more negative than the outside of the neuron membrane.

## NEGATIVE ORGANIC IONS

- Many organic compounds in the neuron cytoplasm also carry negative charges.
- These ions include **some amino acids, many proteins, and RNA.**
- Their presence in the neuron cytoplasm makes the inside of the neuron more negative than the outside.

## LEAKAGE OF $K^+$ IONS

- The neuron cell membrane has many channel proteins called gates. $K^+$ ions continuously leak through leaky $K^+$ gates.
- $K^+$ ions are continuously moved out of the neuron through non-voltage regulated gates.




- This makes the outside of neurons more positive than the inside.
- Overall, more positive charges are on the outside than the inside, known as the resting membrane potential. This potential is maintained until the membrane is disturbed or stimulated by a sufficiently strong stimulus (threshold), which then produces an action potential.

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- In nerve impulse conduction, electrochemical means that it uses electricity made with chemical ions and molecules (Na, K, and charge bearing organic molecules).
- The transmission of impulse along the neuron requires the movement of ions across the membrane.
- This is carried out by tiny holes called channels.
- These **channels** basically are of **two different types**, i.e. pumps and gates.
- **Pumps** perform active transport while **gates** are responsible for facilitated diffusion.
- Some gates operate only under specific conditions (voltage-regulated gates), while others function continuously (non-voltage-regulated gates).

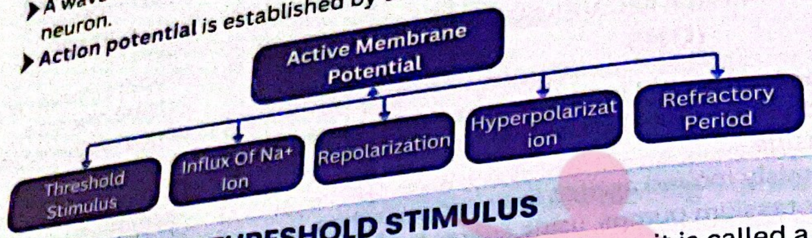
**Types of Nerve Impulses**

**1. Continuous Impulse**

- In non-myelinated neuron fibers, $K^+$ and $Na^+$ ions move across the membrane along the entire

## ACTIVE MEMBRANE POTENTIAL

- Active membrane potential (also called action potential) is characterized by a more positive inside of the neuron than outside (depolarized state).
- This occurs when positive charges move inside the neuron upon receiving a particular stimulus.
- This electrochemical change appears in a short region of the neuron for a brief period, followed by the recovery of the **polarized state**.
- A wave of action potential then moves toward the other end of the neuron.
- **Action potential** is established by the following factors:




### THRESHOLD STIMULUS

- If a stimulus can produce an action potential in a neuron, it is called a **threshold stimulus**.
- If a stimulus cannot excite or fails to elicit any response, it is called a **sub-threshold stimulus**.

### INFLUX OF $NA^+$ IONS

- When a neuron fiber is stimulated by a threshold stimulus, it causes the opening of **voltage-regulated $Na^+$ gates**.
- As a result, $Na^+$ gates permit the **influx of $Na^+$ ions** by diffusion.
- Since more $Na^+$ ions enter than leave, the membrane's electrical potential changes from **-70 mV** towards zero and then reaches **+50 mV**.
- This reversal of polarity across the membrane is called **depolarization**.
- This **electropositive inside** and **electronegative outside** state lasts about **1 millisecond** until the $Na^+$ gates close.

### REPOLARIZATION OF NEURON FIBRE

- A fraction of a second after the sodium gates open, **depolarization** of the axon membrane causes **potassium gates** to open.
- Potassium (**$K^+$**) diffuses out of the cell.
- Since potassium is positively charged, this makes the inside of the cell more negative and starts **repolarization**.

### HYPER-POLARIZATION

(More $K^+$ ions are on the outside than $Na^+$ ions on the inside)

- At the peak of the action potential, the sodium gates begin to close.
- **Sodium permeability** declines.
- The **sodium-potassium pump** continues to work, gradually restoring the original **resting potential**.
- This repolarization is shown by the falling phase of the action

length of the neuron, allowing the action potential to flow as a wave.

- This type of impulse is called a continuous impulse.

**2. Saltatory Impulse**

**BTB**

**OSCILLOSCOPE**

- It is an instrument with a screen which displays changes in the voltage on both side of plasma membrane of neuron with time.

**RMP**

- Many large negative organic compounds are present on both sides of the neuron's plasma membrane. These organic ions include **proteins, amino acids, RNA, $SO_4^{2-}$, $PO_4^{3-}$**, etc.
- These negative ions are much more concentrated inside the membrane than outside, where $Cl^-$ ions are present.

**THRESHOLD STIMULUS**

- It is also known as adequate stimulus (about -50 to -55 mV electric membrane potential).

potential spike, returning the membrane potential to its original level.
- There is a slight overshoot into a more negative potential than the original resting potential, called **hyperpolarization**.
- This is due to the slight delay in closing all the potassium gates compared to the sodium gates.
- As potassium ions continue to exit the axon, their positive charge restores the normal resting potential.

## REFRACTORY PERIOD

- After an action potential, the nerve fiber undergoes a **refractory period** to regain its original ionic distribution and polarity, preparing for the next stimulation.
- Although a repolarized neuron fiber has the same polarity as a polarized neuron fiber, it has a different ionic distribution: more $K^+$ outside and more $Na^+$ inside.
- The repolarized nerve fiber undergoes a refractory period of a few milliseconds during which the sodium-potassium pump actively transports **$Na^+$ ions** out and **$K^+$ ions** in.
- This returns the membrane to its resting potential (from **+50 mV** to **-70 mV**).
- The refractory period lasts about **4 milliseconds**, allowing a neuron to conduct **250 impulses per second**.

## VELOCITIES OF NERVE IMPULSE

- **Velocities** of nerve impulses in the axon membrane and synaptic cleft are variable.
- In human **non-myelinated fibers**, nerve impulses travel at **1-3 m/s**.
- Myelinated fibers conduct at speeds of up to **120 m/s**.
- The velocity of nerve impulses is faster in myelinated neuron fibers due to **saltatory conduction**.
- It is up to **50 times faster** than conduction through the fastest unmyelinated axons because impulses don't have to travel through every single space before moving to the next.
- Another reason myelinated fibers conduct impulses faster is that the **myelin sheath** acts as an insulating layer, preventing energy loss, so myelinated neuron fibers require less energy.
- The velocity of nerve impulses also depends on the **diameter** of neuron fibers.
- **Thick neuron fibers** conduct impulses faster than thin fibers because resistance to electrical current flow is inversely proportional to the cross-sectional area of the conductor; thus, increased thickness decreases resistance to nerve impulses.
- The short journey across the synapse takes about **1 millisecond**, longer than a nerve impulse takes to travel the same distance.
- This time is called **synaptic delay**.

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**ROLE OF LOCAL CIRCUITS IN SALTATORY CONDUCTION OF NERVE IMPULSE**

- The local circuits explain how the **action potential (AP)** is transmitted along the neuron.
- Essentially, an **action potential** at a point in the axon develops a **local circuit** because the influx of **sodium ions ($Na^+$)** at that point makes it positively charged.
- However, regions around that point remain negatively charged (still in the **resting potential** state).
- The **$Na^+$** ions at the AP point are attracted to these negatively charged regions, setting up a **local circuit** there.
- This circuit then opens the **sodium channels** at these points, allowing **$Na^+$** ions to flow in, and the entire **AP cycle** continues, causing the **AP** to move along the axon.

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## SODIUM AND POTASSIUM IONS

- Of the many kinds of ions present in the nerve cells and the

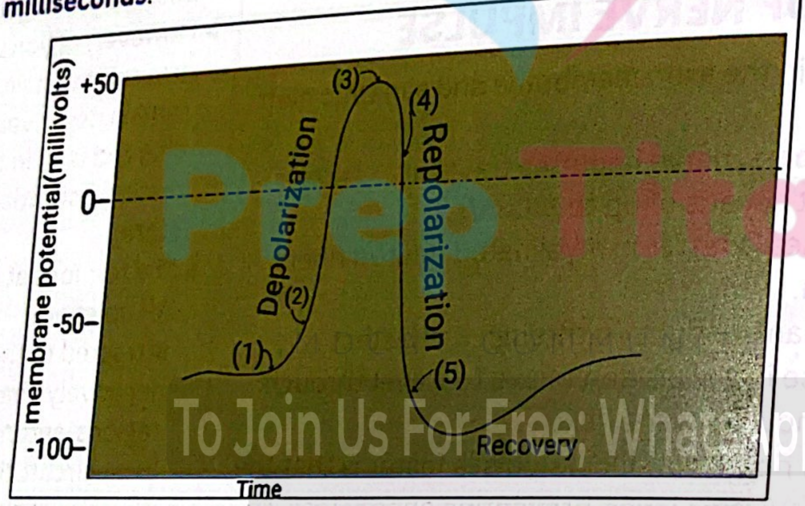
surrounding fluid, sodium ($Na^+$) and potassium ($K^+$) ions are the most important.
- Potassium ions are twenty times more concentrated inside than outside.

## LEAKAGE OF $K^+$ IONS FROM NEURONS

- The cell membrane is virtually impermeable to all ions except $K^+$.
- Since the membrane is slightly permeable to $K^+$, some of it leaks out of the cell.

## AMP

- Active membrane potential of +0.05V or +50mV exists.
- Sequence of membrane potential changes associated with an action potential:
- (1) resting potential (polarized state).
- (2) sodium gates open and $Na^+$ diffuses into the cell, causing a depolarization of the membrane.
- (3) Sodium gates close and potassium gates open.
- (4) $K^+$ diffuses out, causing a repolarization of the membrane.
- (5) sodium - potassium pump restores original ion gradients and resting potential (recovery). Steps **(2) - (5)** take a mere **2-3 milliseconds.**






## SALTATORY IMPULSE

- In myelinated neuron fiber, the myelin sheath is impermeable to $K^+$ and $Na^+$ ions, so prevents the ionic exchange and depolarization fiber along the whole length of neuron.
- The ionic exchange and depolarization occur only at nodes of Ranvier.
- So, the action potential is conducted from node to node in a jumping manner.
- This kind of jumping impulse is called saltatory impulse.

## SPEED OF NERVE IMPULSE

- The speed of nerve impulse is different in different neuron fibers and depends upon the morphology of nerve fibers.
- Average speed of nerve impulse is **100 to 120 meter per second.**

## SYNAPSE

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- Synaptic cleft is cleaved shaped.
- Presynaptic neuron is called transmiting neuron and post synaptic is called receiving neuron.

**SYNAPTIC VESICLES**

- Each of these vesicles has as many as **10,000** molecules of a neurotransmitter substance.
- The dendrite of post synaptic neuron lacks synaptic vesicles.

- Consecutive neurons are arranged so one neuron's **axon endings** connect to the next neuron's **dendrites**, transmitting information called a **synapse**.
- There is no **cytoplasmic connection**; microscopic gaps known as **synaptic clefts** exist.
- Each contact point is a **synapse**.

## STRUCTURE OF SYNAPSE

- Neurons do not directly contact at synapse; **a synaptic cleft** separates them.
- A single neuron may form **synapses** with many incoming fibers from different neurons.
- The neuron sending the impulse is **presynaptic**, while the receiving neuron is **postsynaptic**.

## MECHANISM OF SYNAPTIC TRANSMISSION

- **Synaptic transmission** is the movement of impulses across the **synapse** via **neurotransmitters** (chemical messengers).
- The axons usually have several rounded **synaptic knobs** at their distal ends, which dendrites lack.
- These knobs contain numerous membranous sacs, called **synaptic vesicles** and when a nerve impulse reaches a knob, some of the vesicles respond by releasing a neurotransmitter.

## SEQUENCE OF TRANSMISSION OF IMPULSE

- An **action potential** arrives at the **synaptic knob. Calcium channels** open in the **presynaptic membrane**, allowing **$Ca^{2+}$ ions** to rush in due to lower intracellular concentration. As calcium concentration increases, **synaptic vesicles** move toward the membrane.
- **Neurotransmitter vesicles** fuse with the **plasma membrane** of the transmitting cell.
- The fused vesicles release **neurotransmitter molecules** into the **synaptic cleft.**
- **Neurotransmitter molecules** diffuse across the cleft and bind to **receptor molecules** on the **postsynaptic membrane.**
- Binding of neurotransmitters to postsynaptic neuron receptors opens channels, allowing **$Na^{+}$ ions** to diffuse across the postsynaptic membrane.
- As a result, the postsynaptic membrane **depolarizes**, generating an **action potential.**
- This depolarization towards the threshold is called **excitatory postsynaptic potential (EPSP).**
- Once neurotransmitters have acted on the postsynaptic membrane, they are broken down by enzymes like **acetylcholinesterase break acetylcholine** and **monoamine oxidase break adrenaline.**
- At other synapses, neurotransmitters bind to channels selectively permeable to **$Cl^{-}$**, causing **hyperpolarization** called **inhibitory postsynaptic potential (IPSP).**
- **Neurotransmitters** are cleared from the synaptic cleft by **reuptake**, repackaged into vesicles, or metabolized in **neuroglia.**
- **Neurotransmitters** are classified as **excitatory** and **inhibitory.**

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- There are two types of synapses:

**1. ELECTRICAL**

- Electrical synapses are specialized for rapid signal transmission.
- Cells are separated by a synaptic cleft of only **0.2 nm**, allowing an action potential at the presynaptic side to directly depolarize the postsynaptic membrane and trigger its action potential.

**2. CHEMICAL**

- The majority of synapses are chemical, with a synaptic cleft gap of over **20 nm**. Impulses are transmitted between neurons via **neurotransmitters**, with more than **100 known types.**
- Nearly all neurotransmitters fall into a few groups based on **chemical structure.**

## A) EXCITATORY NEUROTRANSMITTERS

- Excitatory neurotransmitters increase membrane permeability to $Na^+$ **ions**, triggering nerve impulses.
- **Acetylcholine** is an excitatory neurotransmitter in the peripheral nervous system, whereas **biogenic amines** (amino acid derivatives) are key in the CNS.
- They include **epinephrine, norepinephrine, serotonin,** and **dopamine,** which also function as hormones.
- **Epinephrine** and **norepinephrine** increase heart rate during stress, whereas **serotonin** and **dopamine** affect sleep, mood, attention, and learning.

## (B) INHIBITORY NEUROTRANSMITTERS

- Inhibitory neurotransmitters decrease membrane permeability to $Na^+$ **ions**, raising the stimulus threshold and reducing nerve impulse transfer to adjoining neurons, e.g., amino acids **GABA** and **glycine.**
- **Endorphins** are peptides that act as both neurotransmitters and hormones, decreasing pain perception.

**PTB**

- A nerve impulse is passed between neurons via the synapse, but a single impulse may not cross. Multiple impulses arriving rapidly or simultaneously from several fibers may be needed to initiate an impulse in the next neuron.
- **Neurotransmitters** are chemicals released at the **axon endings** in the synapse.

**Major Classes Of Neurotransmitters**

- Acetylcholine
- Biogenic Amine
- Amino Acid
- Neuropeptides
- Gases



## BASIC ORGANISATION OF HUMAN NERVOUS SYSTEM

**The Nervous System**

- Central Nervous System (CNS) (receives and processes information ; initiate actions)
  - Brain (receives and processes sensory information; initiates responses; stored memories; generates thoughts and emotions)
  - Spinal Cord (conducts signals to and from the brain; controls reflex activities)
- Peripheral Nervous System (PNS) (transmits signals between the CNS and the rest of the body)
  - Motor Neurons (carry signals from the CNS that control the activities of muscles and glands)
  - Sensory Neurons (carry signals to the CNS from sensory organs)

**BTB**

- **Humans and most animals** (except coelenterates and echinoderms) have a **centralized nervous system,** characteristic of animals from flatworms to chordates.
- The **human nervous system** is the most advanced, enabling complex ideas, language, tool use, information preservation, and high learning and memory capacities.

**BTB**

CNS act as a coordinating center, these lies in the skull (Brain) and above the vertebral column (spinal cord) i.e. in midline of the body.

- Cavity of spinal cord is known as central canal.

**KPK**

The brain is involved more in coordination than spinal cord. Spinal cord also acts as a link between PNS and brain.

### VENTRICLES OF BRAIN

- Human brain possesses four **ventricles** or cavities, which are filled with

- The CNS is a coordinating centre and it lies in the midline of the body, whereas, the PNS transmits information from receptors to CNS and transmits orders and commands from CNS to effectors.
- An outline of divisions of human nervous system is given in figure.

# CENTRAL NERVOUS SYSTEM (CNS)

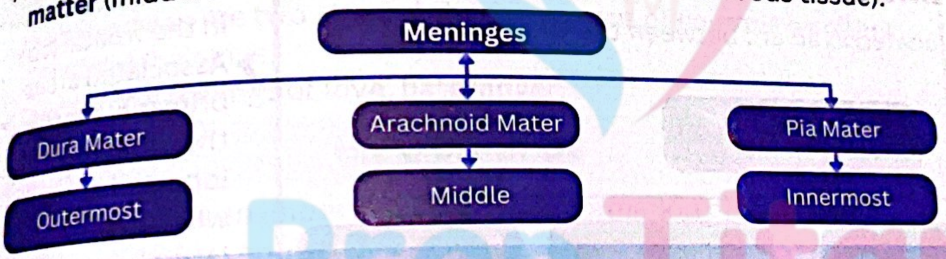
The CNS consists of brain and spinal cord which are hollow and are both protected in three ways.

## 1. SKELETON

- **Cranium** and **vertebral column** protect the brain and spinal cord.
- Cranium is the part of skull that covers (encloses) the brain and protects it.
- Vertebral column consists of **33 vertebrae** that encloses the spinal cord.
- These structures protect against accidents and physical trauma.

## 2. MENINGES

- **Meninges** (singular: meninx) are membranes enveloping the CNS, providing protection.
- The **three meninges** are **dura matter** (next to the cranium), **arachnoid matter** (middle membrane) **pia matter** (next to the nervous tissue).




## 3. CEREBROSPINAL FLUID OR CSF

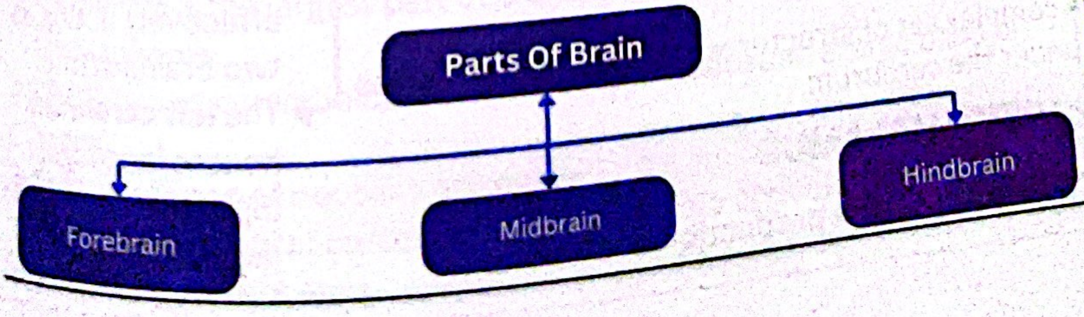
- **CSF** is produced by **diffusion**, **pinocytosis**, and **active transport** from brain and spinal cord blood vessels.
- Found between **pia mater** and **arachnoid mater**, around the surface of brain and spinal cord surfaces, in brain ventricles, and in central hollow canal of spinal cord.
- Functions in **homeostasis** and **metabolism**.



**PTB**

- Neural arches, of vertebrae of vertebral column protect the spinal cord.
- The cerebrospinal fluid (CSF), similar in composition to blood plasma, bathes the neurons of brain and spinal cord and it cushions against the bumps and jolts.

## BRAIN




cerebrospinal fluid.

- The **first and second ventricles** are present between limbic system and cerebrum known as lateral ventricles.
- Another ventricle is present between limbic system and thalamus called **third ventricle** while **fourth ventricle** is present in medulla.
- There is a tube between third and fourth ventricle known as **Iter** or **cerebral aqueduct.** while an opening between lateral ventricles and third ventricle is called **intra ventricular foramen.**

**BTB**

**FOREBRAIN**

- **Forebrain** has two sub-divisions: telencephalon (**cerebrum**) and diencephalon (thalamus, limbic system).

PTB

## FOREBRAIN

*Forebrain is further divided into three functional parts, the thalamus, the limbic system and the cerebrum.*

## THALAMUS

- *It is located below the cerebrum.*

*Functions:*

- *Thalamus carries sensory information to the limbic system and cerebrum.*
- *The information includes sensory input from auditory and visual pathways, from the skin and from within the body.*

FTB

- *It receives all sensory impulses (except sense of smell) and channels them to limbic system and to appropriate regions of cortex for interpretations.*

## LIMBIC SYSTEM

- *The limbic system is located in an arc between the thalamus and cerebrum.*

Parts Of Limbic System
- Hypothalamus
- Amygdala
- Hippocampus
- Nearby Regions Of Cerebrum

## FUNCTIONS

- *It works together to produce our most basic and primitive emotions, drives, and behaviours, including fear, rage, tranquillity, hunger, thirst, pleasure and sexual responses.*
- *It is also involved in the formation of memories.*

## THE LIMBIC SYSTEM AND THALAMUS

- The limbic system extends through several brain regions. It seems to be the centre of most unconscious emotional behaviours, such as love, hatred, hunger, sexual responses, and fear.
- The thalamus is a crucial relay centre among the senses, the limbic system, and the cerebral cortex.

FTB

- The limbic system is a complex set of structures that lies on both sides of the thalamus, just under the cerebrum.

## HYPOTHALAMUS

The hypothalamus through its hormone production and neural

- The human **cerebrum** is the largest among animals, comprising over half of the brain.
- It transfers memory from one side of the brain to the other.
- It controls learning, conscious sensations, decision-making, dreams, emotions, and memory analysis.
- Although motor sensory and associated areas are in all **cerebrum** parts, motor areas are more abundant in the frontal lobe.
- Associated areas primarily occupy the anterior frontal lobe and are widespread in the lateral parietal, temporal, and occipital lobes.
- **Cerebrum** contains more **highest number of neurons** than any other brain part.

### ACCORDING TO "ROGER SPRAY"

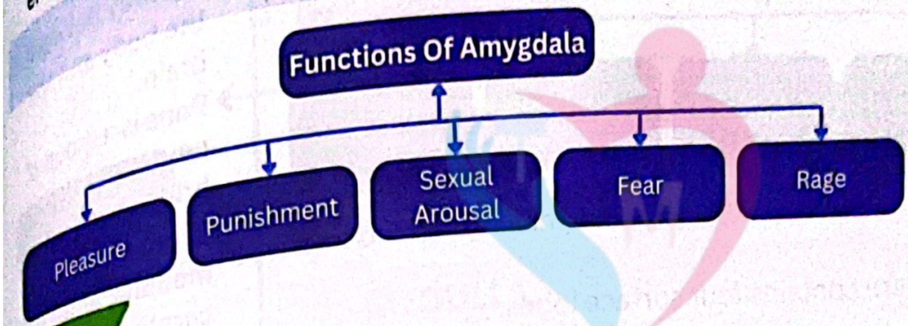
- Although both cerebral **hemispheres** are superficially similar, the right and left function differently, effectively acting as two brains in one.
- The **left cerebrum** houses language, logic, and mathematical

connections acts as a major coordinating centre controlling body temperature, hunger, the menstrual cycle, water balance, the sleep-wake cycle, biorhythms etc.

**FTB**

- On the ventral side of the thalamus is the hypothalamus.
- It maintains homeostasis, blood pressure and sexual response and fight or flight etc.
- Controls pituitary gland and serves as a link between the nervous and endocrine system.

## AMYGDALA




**FTB**

- The amygdalae are two almond shaped masses of neurons on either side of the thalamus.
- They control feelings of love, hate, anger.

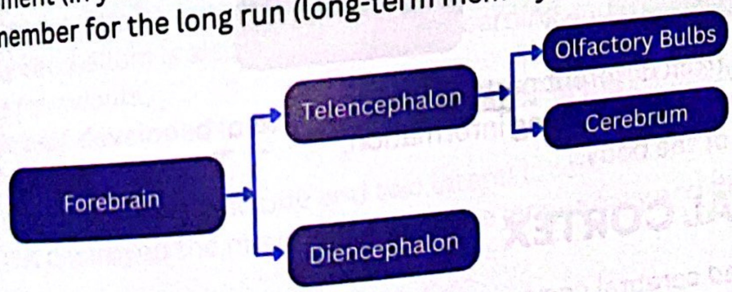
## HIPOCAMPUS

Hippocampus plays an important role in the formation of long-term memory, and thus is required for learning.



**FTB**

- It consists of two horns that curve back from the amygdala. It seems to be very important in converting things that are in your mind at the moment (in your short-term memory) into the things that will you remember for the long run (long-term memory).




## CEREBRUM

- **Cerebrum** is the largest part of the brain, divided into two **cerebral hemispheres.**
- These halves communicate via the **corpus callosum,** a large band of axons.
- Tens of billions of **neurons** are packed into the cerebrum. The outer region, the **cerebral cortex,** forms folds called convolutions, greatly increasing ...

abilities, while the right hemisphere manages imagination, spatial perception, artistic, and emotional abilities.

**KPK**

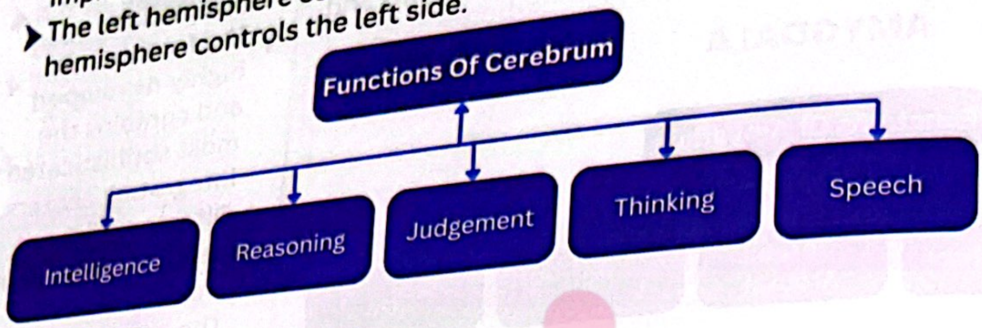
- The **forebrain is highly developed** and contains the most sophisticated integrating centers.
- Olfactory bulbs handle the sense of smell.
- The cerebrum's numerous folds or convolutions may relate to intelligence.
- The **diencephalon** harbors the limbic system, including the thalamus, hypothalamus, amygdala, and hippocampus.

## MID BRAIN

- Midbrain is reduced in humans and contains the **reticular formation,** a network of **neurons** running through the medulla in the hindbrain, through the midbrain, and into the **thalamus** and **hypothalamus** of the forebrain.
- It receives input from most **senses** and sends outputs to higher brain centers, **filtering** sensory information.

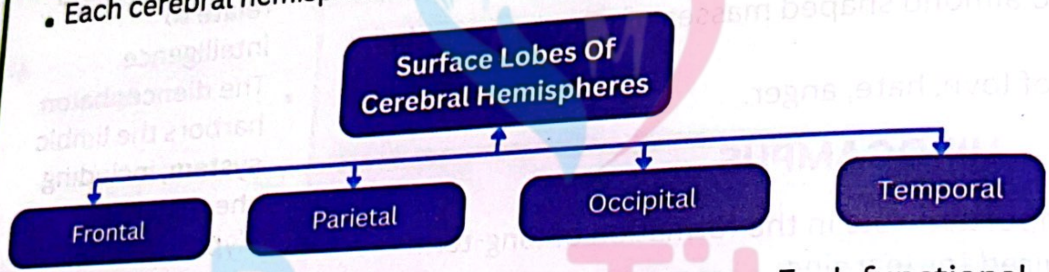
## FUNCTIONS OF CEREBRUM

- *Receives and processes sensory information, storing some in memory for future use.*
- *Directs voluntary movements.*
- *Responsible for thinking (poorly understood process).*
- *The cerebral cortex contains primary sensory areas where signals from sensory organs (eyes, ears) are received and converted into subjective impressions like light and sound.*
- *The left hemisphere controls the right side of the body, and the right hemisphere controls the left side.*

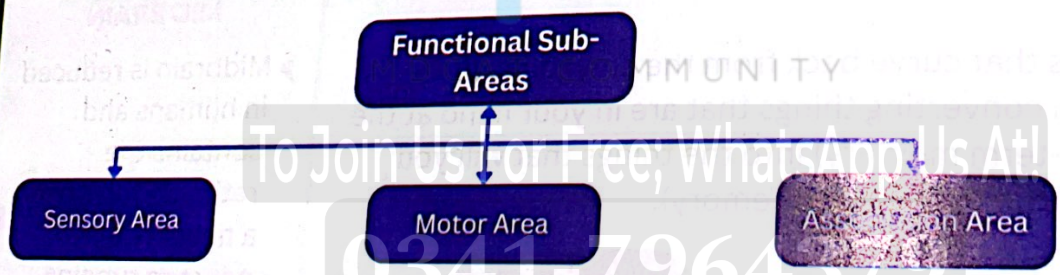



**FTB**

- Each cerebral hemisphere contains four surface lobes.




- Each lobe further contains different functional areas. Each functional area consists of three sub areas:




- **Sensory area** receives impulses from different parts of body.
- **Association area** interprets or analyses incoming information.
- **Motor Area** controls responses of the body.



## CEREBRAL CORTEX

- The surface of cerebrum is called cerebral cortex. It has many folds or convulsions forming ridges or gyri (singular, GYRUS) which are separated by grooves.
- A **shallow groove** is called a **sulcus** (plural, sulci) and a **deep groove** is called as **fissure.**
- The two hemispheres (cerebrum) are separated by longitudinal fissure.
- These grooves greatly increase the surface area of the cerebrum.

### HIND BRAIN

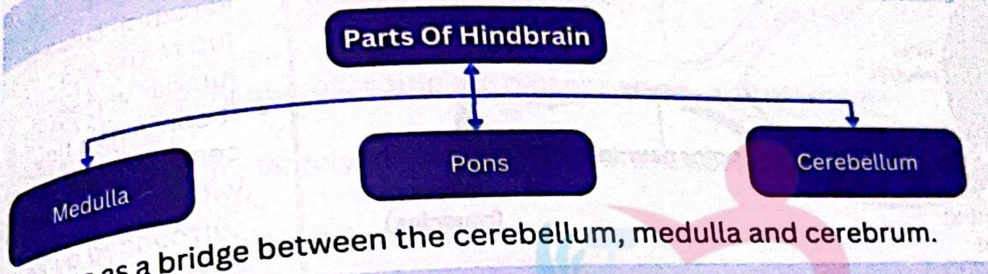
- **Medulla oblongata** is the posterior portion of the brain, broad in front and narrowing behind, where it is continuous to the spinal cord.
- It serves as the **communication** highway between the body and the brain.
- **Pons** is a group of neurons acting as a bridge between the **cerebellum, medulla,** and **cerebrum.**
- **Cerebellum** is the second largest part of the brain, bulb or leaf-like in shape.
- **Medulla** is the last part of the brain but evolutionarily developed **first.**
- The midbrain, along with pons and medulla, form the **brain stem,** which **supports life.**

PTB

## MIDBRAIN

- Midbrain is reduced in humans, and it contains auditory relay centre and centre that controls reflex movements of eyes.
- Midbrain contains **reticular formation**, which is a relay centre connecting hindbrain with the forebrain.
- Reticular formation is very important in screening the input information, before they reach higher brain centres.

## HINDBRAIN




- It acts as a bridge between the cerebellum, medulla and cerebrum.

## MEDULLA

- It controls several automatic functions, such as breathing, Heart rate, blood pressure and swallowing.

## PONS

- Certain neurons in pons, located above the medulla, appear to influence transitions between sleep and wakefulness, and the rate and pattern of breathing.
- It is relatively small in size.

## CEREBELLUM

- The cerebellum is important in **co-ordinating movements** of the body.
- The cerebellum guides, smooth and accurate motions and maintains body position.
- The cerebellum is also involved in the learning and memory storage for behaviours.
- It is **best developed** in **bird**, which is engaged in the complex activity of light.
- It consists of a central lobe and two lateral lobes.
- If it is destroyed the movements become jerky, shaky and disturbed.



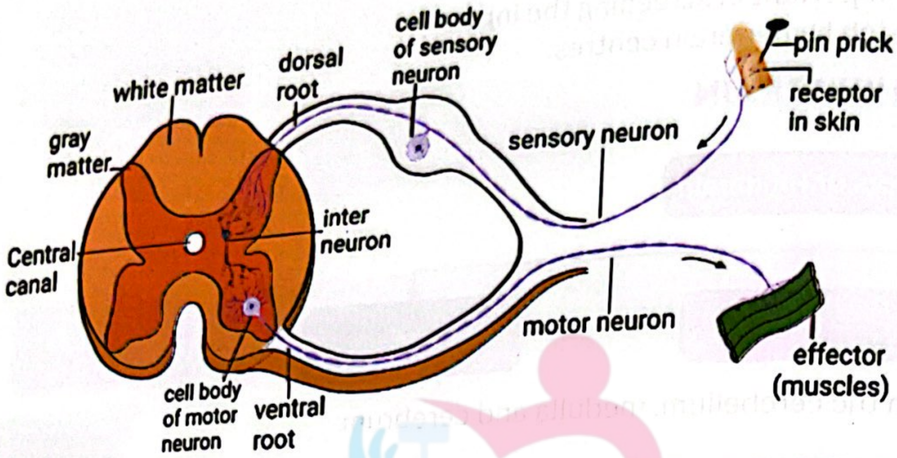
FTB

- Cerebellum controls equilibrium. body position and coordination of the actions of individual muscles to produce complex activities such as walking, running, riding bicycles etc.
- The brain is hollow structure, and it has cavities known as Ventricles.
- There are four ventricles.

**Special Reflexes Of Medulla**

- Salivary Secretions
- Vomiting
- Coughing
- Sneezing

# SPINAL CORD




- Spinal cord is the most vital structure between the body and the brain.
- It extends from the **medulla** to the lumbar vertebrae.
- A transverse section shows **white matter** in the periphery, **grey matter** inside, and a central canal filled with **CSF**.
- Grey matter is "H" or "butterfly" shaped, consisting of **neuron cell** bodies and non-myelinated fibers or tracts.
- The white matter is made up of bundles of myelinated fibres i.e., mostly axons.
- Several pairs of spinal nerves originate from ventral and dorsal horn of grey matter.
- The Dorsal root of spinal nerves, also contain ganglia present just beside the spinal cord.
- Arrangement of grey and white matter in brain is opposite to that of spinal cord.



**PTB**

- **Medulla oblongata** narrows into an oval hollow cylinder, the **spinal cord**, running through the **vertebral column**.
- It is made up of a very large number of neurons, the cell-fibers and bodies of which are arranged in a definite pattern.
- The spinal cord is the center for great many reflexes, and it serves as a pathway for conduction of impulses to and from different parts of the body and brain.

# PERIPHERAL NERVOUS SYSTEM

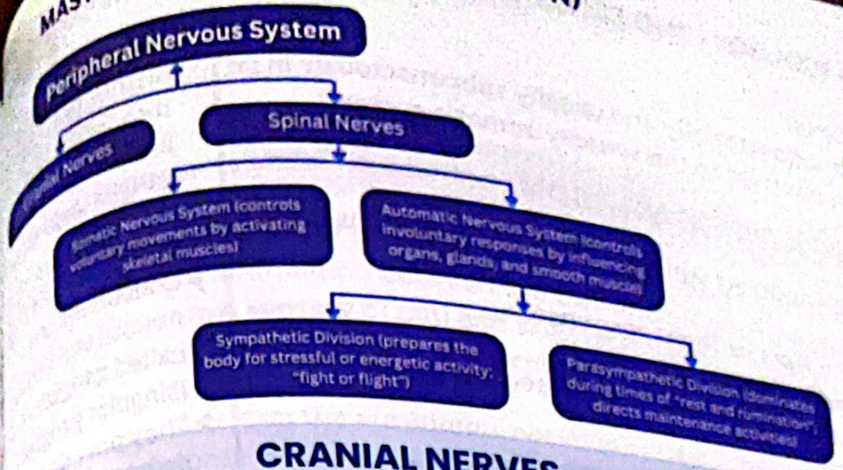
- The peripheral nervous system consists of the nerves that branch out from the central nervous system and connect it to other body parts.
- The peripheral nervous system includes cranial nerves which arise from the brain and spinal nerves, which arise from the spinal cord.

**BTB**

- Spinal cord is an elongated, hollow, fluid-filled cylindrical structure extending from the **foramen magnum** (a hole in the skull's base) into the neural canal of the **vertebral column** (up to the **2nd** lumbar vertebra).
- It contains a tiny central **canal** filled with **CSF**, surrounded by an ependymal layer (a single cell layer).
- **Local anaesthesia** is administered at the fourth lumbar to protect the **spinal cord**.
- The spinal cord controls reflexes below the neck.
- It helps in better function of brain.

## HUMAN BRAIN & COMPARE ITS CS WITH THAT OF SPINAL CORD

- Both brain and spinal cord consist of **white and grey matter**.
- In the brain, grey matter lies mostly outside (**cerebral cortex**) and white matter inside (**cerebral medulla**). In the spinal cord, grey matter is inside (butterfly-shaped) and white matter outside.




## CRANIAL NERVES

- There are **twelve pairs** of cranial nerves.
- Some are **sensory nerves**, some are **motor nerves**, and others are **mixed nerves**.
- **Cranial nerves** are largely concerned with the **head**, **neck**, and **facial regions** of the body.
- They are also called **cerebral nerves**.

## SPINAL NERVES

- **Thirty-one** pairs of spinal nerves originate from the **spinal cord**.
- They are all **mixed nerves**, providing **two-way communication** between the spinal cord and parts of the **arms**, **legs**, **neck**, and **trunk**.
- Each spinal nerve emerges from the spinal cord by two short branches or roots, which lie within the **vertebral column**.
- The **dorsal root** contains fibers of **sensory neurons**, conducting impulses to the spinal cord.
- The **ventral root** contains fibers of **motor neurons**, conducting impulses away from the cord.
- The two roots join just before a spinal nerve leaves the vertebral column.
- Each spinal nerve serves the **specific region** of the body where it is located.

## SOMATIC AND AUTONOMIC NERVOUS SYSTEM

- The peripheral nervous system can also be subdivided into the somatic and autonomic nervous systems.

## SOMATIC NERVOUS SYSTEM

- The somatic nervous system consists of cranial and spinal nerve fibers that connect the **CNS** to the **skin** and **skeletal muscles**; it is involved in **conscious activities**.

## TITLE

- The autonomic nervous system includes fibers that connect the CNS (especially the **hypothalamus** and **medulla oblongata**) to the **visceral organs** (heart, stomach, intestines, glands).
- It is concerned with **unconscious activities**.
- The autonomic system is divided into **sympathetic** and

**KPK**

### SPINAL CORD

- The **spinal cord** is the central cable of the nervous system.
- It is approximately **18 inches long** and **half an inch** wide.
- **Continuous** with the brain at the front, it tapers posteriorly, lying in the **canal of urostyle**.
- The central canal connects with brain cavities but ends blindly behind.
- Covered by a thin pigmented **pia mater** and the neural canal is lined with a thick, tough **dura mater**; the space between contains **lymphatic fluid** protecting the cord from shocks.

### FUNCTIONS

- Conducts **sensory impulses** from skin and muscles to the brain.
- Carries **motor impulses** from the brain to neck and limb muscles.
- Receives commands from the brain to control **trunk** body parts.

**KPK**

### PERIPHERAL NERVOUS SYSTEM

- The **PNS** comprises **sensory** and **motor**

parasympathetic systems.

- Both systems function **automatically** and usually **subconsciously** in an involuntary manner (in contrast to the **sensory somatic system**).

## SYMPATHETIC DIVISION

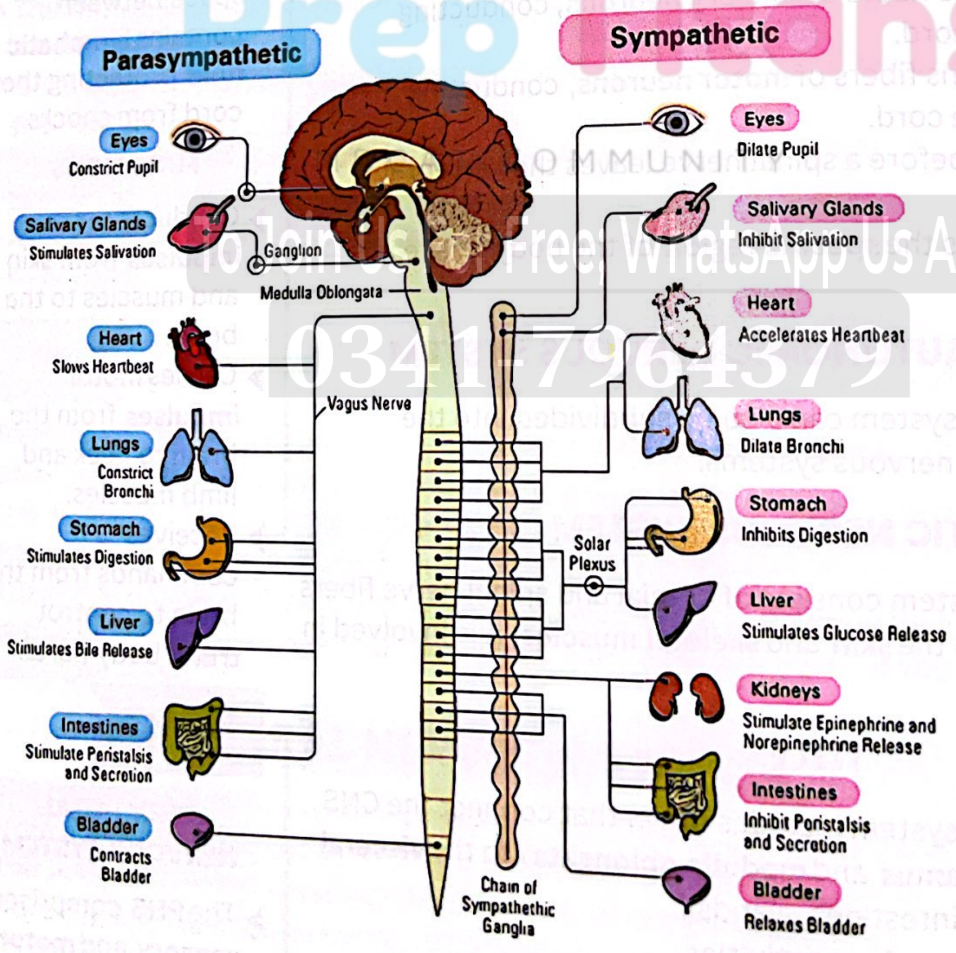
- The sympathetic division controls various **autonomic functions** during emergencies.
- It prepares the body for a **fight or flight** response.
- It consists solely of **spinal nerves**.
- These nerves arise from the first **thoracic** to the second **lumbar** segments of the spinal cord.

## PARASYMPATHETIC DIVISION

- A few **cranial nerves**, including the **vagus nerve**, and nerves from the **sacral (bottom)** region form the **parasympathetic division**.
- It controls autonomic functions during **rest**.
- It restores body functions to normal after **sympathetic** stimulation.
- In danger, the sympathetic system prepares the body for activity; the parasympathetic system reverses these changes when the danger is over.

## SYMPATHETIC AND PARASYMPATHETIC NERVOUS SYSTEM

- Both systems function **automatically**, innervate all **internal organs**, and utilize **two neurons** with **one ganglion** per impulse.




neurons, distributed throughout the body in form of **ganglia and nerves**.

### GANGLIA

- Collections of **neuron cell bodies** called **ganglia**. (singular **ganglion**).
- They provide **relay points** and intermediary connections between neurological structures like the **PNS** and **CNS**.
- Ganglia often interconnect to form a **plexus** **(complex system of ganglia)**.

### NERVES (TRACTS)

- Bundles of **neuron fibers** (dendrites or axons) covered by **connective tissue** are called **nerves**.
- Communication between **receptors** and the **CNS**, and from **CNS** to **effectors**, is carried out by **nerves**.
- **Nerves** can be classified based on **function** and **origin**.
- Functionally, they are three types:

### SENSORY NERVES

- These nerves carry impulses from **receptors** to the **CNS**.

### MOTOR NERVES

- These nerves carry impulses from **CNS**

PTB

- Motor neurons form the somatic nervous system, controlling voluntary movements under conscious control, involving skeletal muscles.
- The somatic system is part of the peripheral nervous system, carrying sensory and motor information between the CNS and voluntary parts like the skin (external sensory organ) and skeletal muscles.
- Reflex reactions of skeletal muscle are involuntary responses to external stimuli (thus an exception).
- Motor neurons also form the autonomic nervous system, controlling involuntary responses by influencing organs, glands, and smooth muscles.

to the effectors

**MIXED NERVES**

These nerves are the groups of sensory and motor nerves.

BTB

- Only the 10th cranial nerve, named vagus, has branches to the pharynx, larynx, and most internal organs.

## SYMPATHETIC SYSTEM

- Most ganglion fibers of it arise from the middle portion of the spinal cord and terminate in ganglia that lie near the cord.
- It **accelerates the heartbeat, dilates pupils, inhibits digestion**, and **raises blood pressure (BP)**.

## PARA SYMPATHETIC NERVOUS SYSTEM

- It promotes internal responses associated with a **relaxed state**, such as **contraction of pupils, promotes digestion, retards heartbeat**, and **lowers BP**.

KPK

## CRANIAL NERVES

- Cranial nerves which pass through the foramen (an opening) of the skull and mainly supply the peripheral tissues in the head except vagus nerve which extends event up to the abdomen.
- Functionally, **three pairs** of cranial nerves are sensory in nature (**I, II, VIII**), **five pairs** are motor in nature (**III, IV, VI, XI, XII**), and **four pairs** are mixed in nature (**V, VII, IX, X**).

## AUTONOMIC NERVOUS SYSTEM

- Consists of both sensory neurons and motor neurons that runs between central nervous system and many viscera like lungs, heart and glands.
- The autonomic nervous system also controls the contraction of cardiac and smooth muscles (done by motor neurons).

## SYMPATHETIC NERVOUS SYSTEM

- Increases metabolism to avoid danger.
- Preganglionic fibers are short and postganglionic long.

## PARASYMPATHETIC NERVOUS SYSTEM

- Maintain body homeostasis, i.e. returns body functions to normal position.
- Preganglionic fibers are long and postganglionic short.

# CHAPTER 14 CHEMICAL COORDIATNIONS

## Chemical Coordination

- Cellular functions require continuous regulation. Since nerve fibers do not innervate all body cells, a special coordination system is necessary.
- The **endocrine system** coordinates most body cells.
- The **hormonal system** controls various **metabolic functions** such as chemical reaction rates, substance transport through cell membranes, growth, and secretions. This coordination is termed chemical coordination.
- In animals, it involves the **endocrine system**, comprising glands in various body parts that secrete **hormones**.
- The **endocrine or ductless glands** are, with a few exceptions, discrete groups of cells, which make specific chemical compounds called **hormones** (Greek hormone is exciting, setting in motion).
- The endocrine system consists of some **20 endocrine glands/tissues** lying in different parts of the body.

## HORMONES

- **Glands** produce and release **secretions.**
- There are two types of glands: **exocrine glands** and **endocrine glands.**
- **Endocrine glands** or ductless gland secrete **hormones** that affect cells in other body parts.
- A **hormone** is a small, soluble organic molecule effective at low concentrations.
- It acts as a **chemical messenger**, transporting signals from one cell to another.
- **Hormones** exert their effects at specific sites where **receptors** are present, known as **targets**; hence it is termed as messenger.



**FTB**

- In **1902**, **Bayliss and Starling** extracted a substance from the **duodenum** that stimulated pancreatic digestive juice secretion when injected into the bloodstream.
- They named the substance **'secretin'** and coined the term **'hormone'**, meaning "to excite" or "set in motion."

**PTB**

- **Hormones** are organic compounds with varying structural complexities.
- They are released directly into the **blood** and transported to respective **target tissues.**
- Hormones affect **target cells** without initiating new biochemical reactions but regulate existing **enzymatic** and other **chemical reactions.**
- They may **stimulate** or **inhibit** functions.

**BTB**

- **Hormones** also affect **exocrine glands** or individual cells/tissues that secrete chemical substances.
- **Exocrine glands** secrete substances like **digestive enzymes, milk, sweat,** and **bile,** routing their secretions to specific destinations via **ducts.**
- **Endocrine hormones** travel within the **bloodstream** and affect cells in other body parts.
- **Local hormones** do not travel in the bloodstream but affect nearby cells, e.g., **serotonin, prostaglandin,** and **gastrointestinal hormones.**
- **Hormones** can **increase, decrease,** or **modify** the secretion of other glands.
- They also increase or decrease body structure.

- Hormones also control long-term changes, such as **growth rates**, **metabolic activity**, and **sexual maturity**.

## PHEROMONES

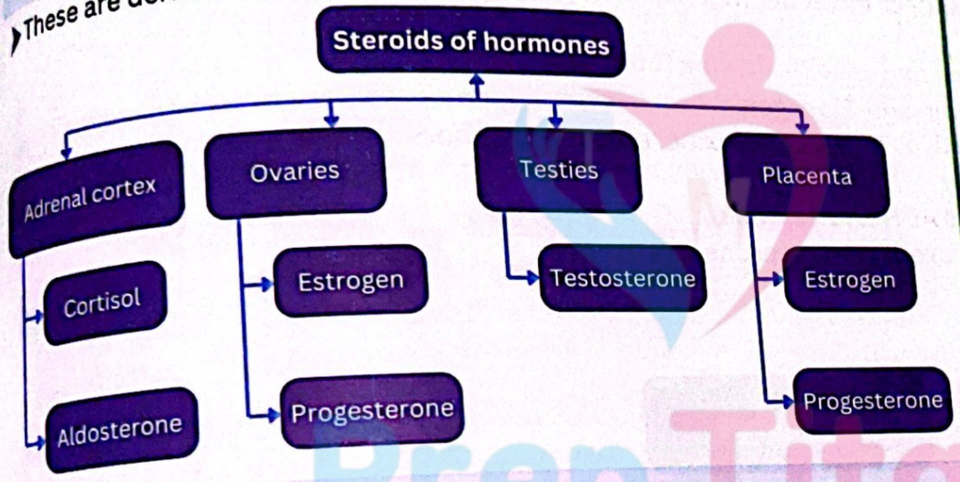
- They are hormone-like chemical messengers but removed outside the body.
- These are small, volatile chemicals that function in communication among animals and fungi.
- They act by influencing the physiology and behavior of the receiving individuals.

# TYPES OF HORMONES

- Chemically, hormones are of **three basic** types i.e. steroids, amino acids or their derivatives, and proteins or polypeptides.

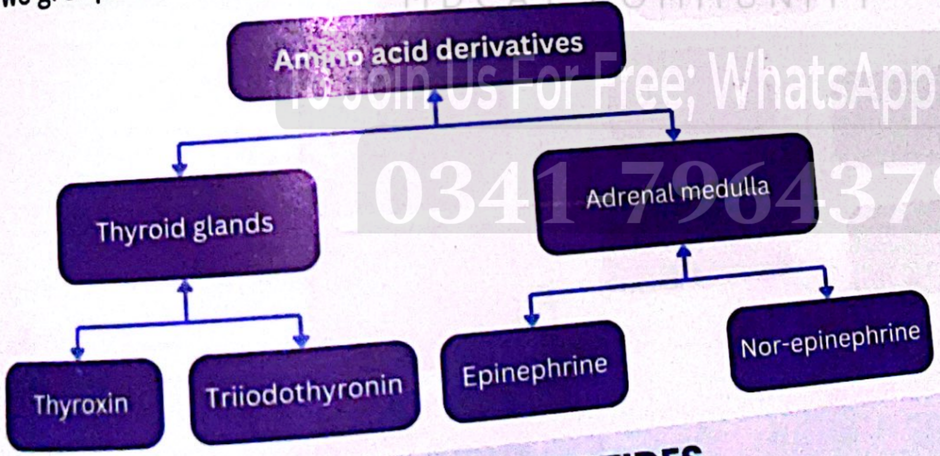
## STEROID HORMONES

- These are derivatives of cholesterol.




## DERIVATIVES OF AMINO ACID TYROSINE

- Two groups of hormones are derivatives of amino acid tyrosine.




## PROTEINS OR PEPTIDES

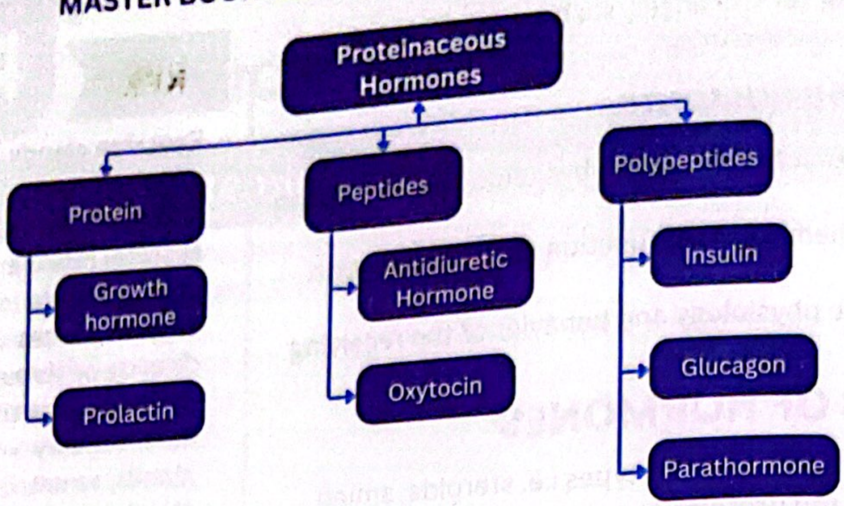
- Many important endocrine hormones are proteins, peptides or immediate derivatives of these.
- Growth hormone and prolactin are protein while antidiuretic hormone and oxytocin are peptides of nine amino acids each.

**KPK**

- **Exocrine glands** ("exo" meaning outside; "crine" to secrete) release products onto target surfaces directly or through **ducts**, such as the **liver**, **salivary glands**, **sweat glands**, and **tear glands**.
- Unicellular **Goblet cells** directly release **mucin** via **exocytosis**.
- **Endocrine glands** ("endo" meaning within; "crine" to secrete) are **ductless glands**.
- They produce **hormones** and secrete them by **exocytosis** directly into **extracellular spaces**.
- From there, hormones enter the **blood** or **lymphatic fluid** and travel to specific **target sites**.

**BTB**

Chemically, there are **three basic types of hormones**, which are:
- Steroid
- Amino acids or their derivatives, proteins and glycoproteins.
- Few belong to the fatty acids e.g., prostaglandin
- **Glycoprotein hormones** are

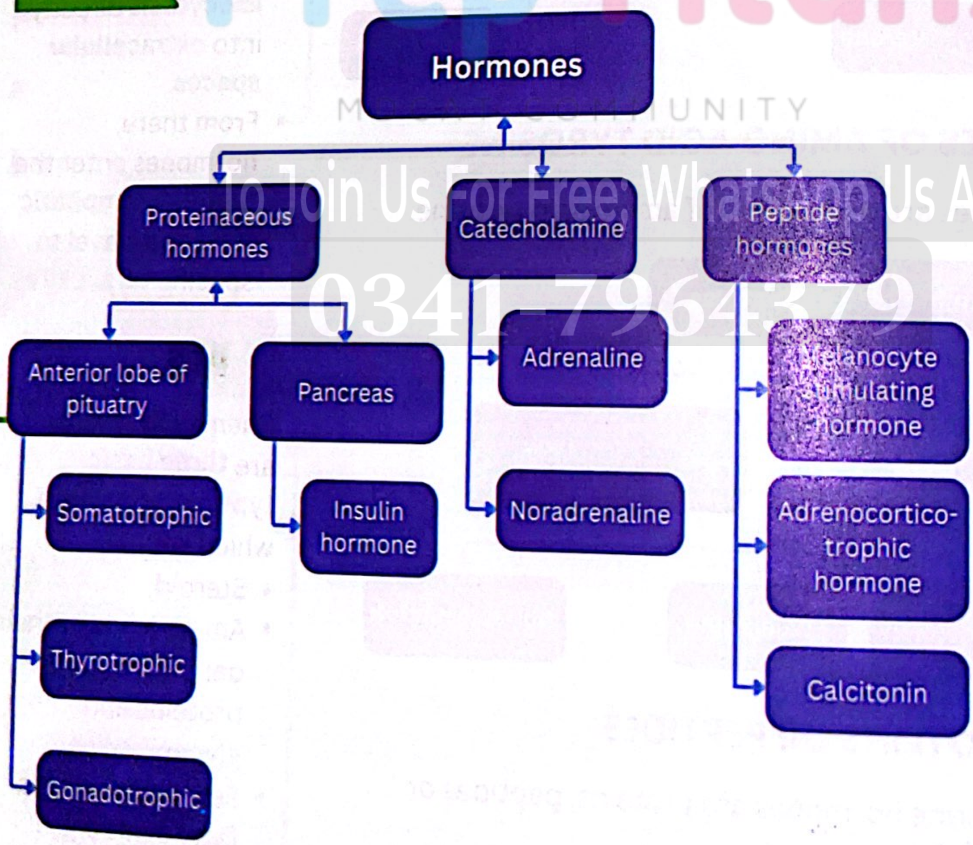



Follicle Stimulating Hormone (FSH), Luteinizing Hormone (LH), human chorionic gonadotropin (HCG) and Thyroid stimulating hormone (TSH).

**PTB**

- A hormone is a messenger molecule that can stimulate an immune response
- **Chemically hormones may be of following four types:**
- **Proteins** include Insulin and Glucagon.
- **Amino acids & derivatives** include thyroxine, epinephrine, nor-epinephrine.
- **Polypeptides** includes ADH and oxytocin.
- **Steroids** includes estrogens, testosterone, cortisone.

**FTB**






## MODE OF ACTION OF HORMONE

➤ There are two modes of action of hormones.

## 1. FIXED MEMBRANE RECEPTOR MECHANISM

- Peptide and protein hormones cannot pass through the cell's plasma membrane as they are **water-soluble.**
- They bind to **receptors** on the plasma membrane of the target cell, initiating a series of intracellular steps.
- **Adenylate cyclase**, an enzyme in the plasma membrane, catalyzes the transformation of **ATP** into the second messenger, **Cyclic Adenosine Monophosphate (cAMP).**
- cAMP triggers various cellular changes, including **enzyme activation** and **gene activation (signal transduction).**

## 2. MOBILE RECEPTOR MECHANISM (GENE/SIGNAL MODULATION)

- Steroid and amino acid derivative hormones can pass through the plasma membrane as they are **lipid-soluble.**
- Their **receptors** are located inside target cells, either in the **cytoplasm** or **nucleus.**
- The hormone and receptor form a **hormone-receptor complex**, acting as a **transcription factor**, which travels to the specific **gene.**
- The transcription factor binds to the **promoter region** of the gene.
- The **target gene** is transcribed into **messenger RNA (mRNA)** and then translated into **polypeptide (protein)** in the cytoplasm.
- Thus, target cell activities are modified by altering **gene expression.**

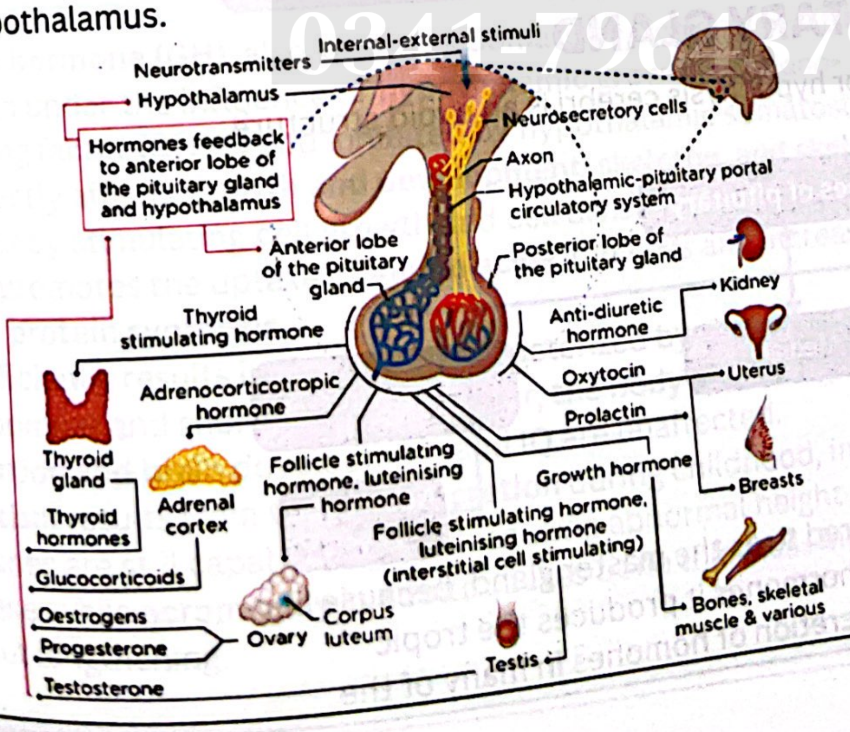
## ENDOCRINE GLANDS OF HUMANS

- The human endocrine system includes about **20** different endocrine glands, some of which are hypothalamus, pineal, pituitary, thyroid, parathyroids thymus, adrenal, pancreatic islets and gonads.

## NEUROSECRETORY ROLE OF HYPOTHALAMUS

- The **hypothalamus** is part of the **forebrain**, where many **sensory** stimuli are converted into **hormonal responses.**
- **Oxytocin** and **antidiuretic hormone (ADH)** are produced in the hypothalamus and travel down nerves to the **posterior pituitary** for storage.
- They are released from storage upon receiving **nerve impulses** from the hypothalamus.





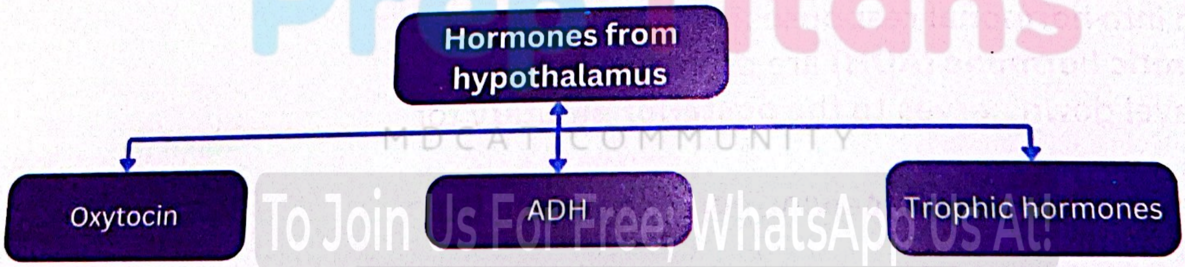
- Neurosecretory cells in the hypothalamus produce and secrete various hormones.
- One nerve cluster synthesizes oxytocin and vasopressin, storing them in nerve endings in the posterior pituitary.
- Upon stimulation from the brain, **oxytocin** and **vasopressin** are released into the **blood supply** of the posterior pituitary.
- Other nerve clusters produce and secrete **releasing** and **inhibiting hormones**, carried by the blood to the **anterior pituitary**.
- There, they regulate the secretion of **tropic hormones**, **growth hormones**, and **prolactin** from anterior pituitary cells.

**FTB**

- The **hypothalamus** regulates physiological functions such as **hunger, thirst, sleep,** and **temperature.**
- It monitors **metabolites** and **hormone levels** in the blood.
- The hypothalamus is the **master control center** of the **endocrine system.**
- Its endocrine signals directly control the **pituitary gland**.
- It contains special groups of **neurosecretory cells.**
- These cells conduct **impulses** and have high **secretory capacity**.
- The hormones produced are either **releasing factors** that stimulate pituitary hormone secretion or **inhibiting factors** that inhibit it.
- They are produced in the **cell bodies**, packed into **granules**, and transported down the **axon** by **cytoplasmic streaming.**
- The axon endings synapse with **blood capillaries** and release hormones into the blood when stimulated.

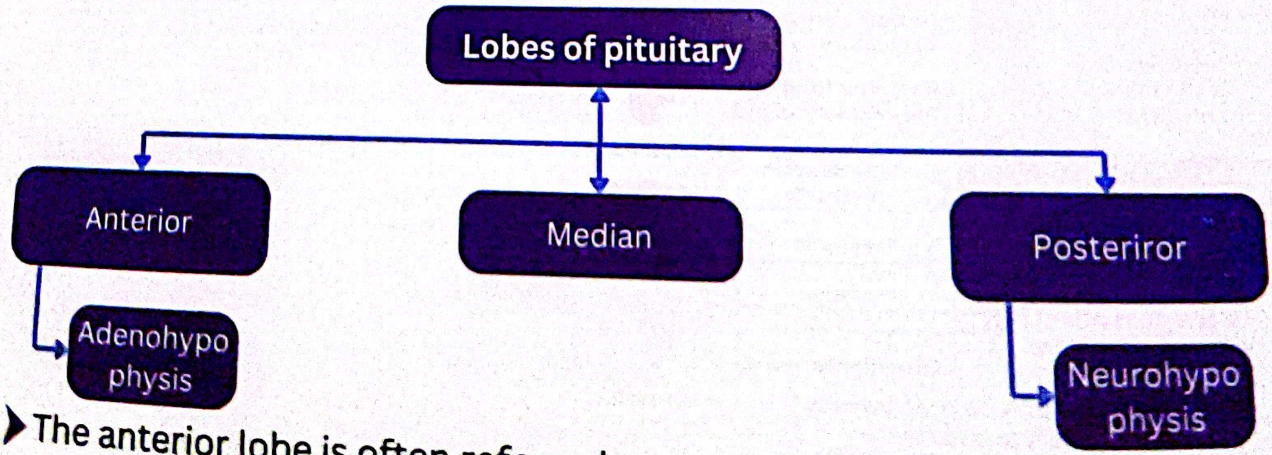
## HYPOTHALAMIC HORMONES AND THEIR EFFECTS






## PITUITARY GLAND

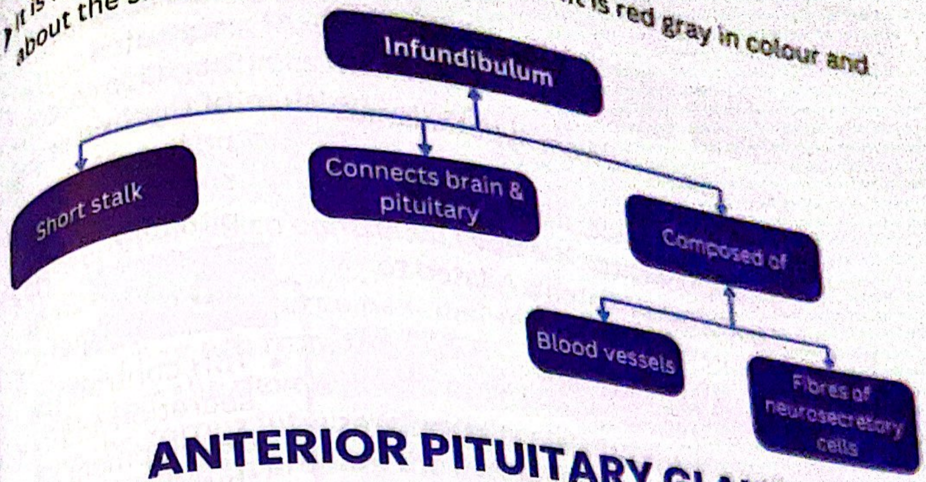
- In man, the pituitary gland or hypophysis cerebri is an ovoid structure about **0.5 gm** in the adult



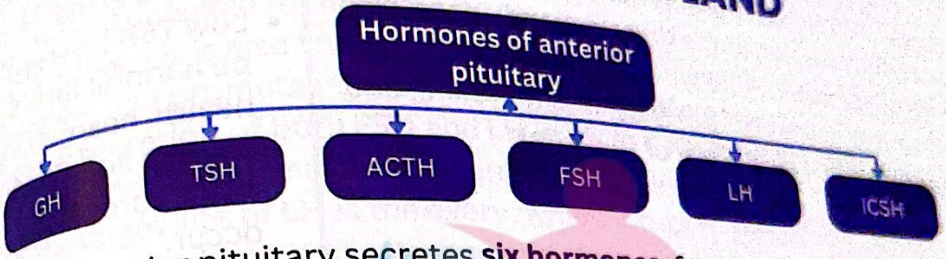

- The anterior lobe is often referred to as the master gland, because in addition to producing primary

other endocrine glands.

- It is located just below the hypothalamus. It is red gray in colour and about the size of a pea.




## ANTERIOR PITUITARY GLAND



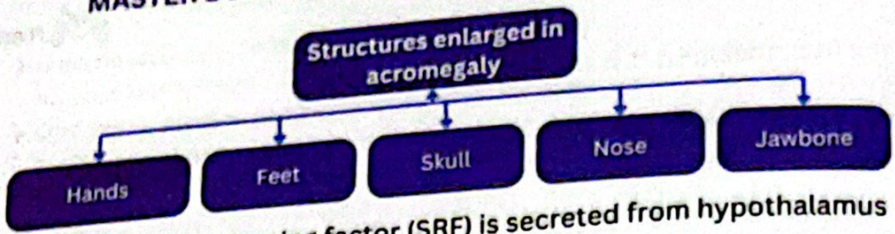

- The anterior pituitary secretes **six hormones**, four of which are **tropic hormones**.
- **Tropic hormones** (Tropi=turn on, change) regulate the secretory actions of other **endocrine glands**, earning the anterior pituitary the title of **master gland**.
- The **tropic hormones** include **thyroid-stimulating hormone (TSH)**, **adrenocorticotropic hormone (ACTH)**, **follicle-stimulating hormone (FSH)**, and **luteinizing hormone (LH)**.
- The other two hormones are **primary hormones**, such as **growth hormone (GH)** and **prolactin (PRL)**, which directly affect **body structure** or **exocrine glands**.



## GROWTH HORMONE (GH) OR SOMATOTROPIC HORMONE (STH)



- **Growth hormone (GH)**, also known as **Somatotropic hormone (STH)**, is released under the influence of **hypothalamic growth hormone-releasing factor (GHRF)** and inhibited by hypothalamic somatostatin.
- **GH** directly affects **growth and development**, **skeleton**, and **skeletal muscles** by stimulating **cell growth** and cell division.
- It also promotes the uptake of **amino acids** into cells and increases the rate of **protein synthesis**.
- **GH deficiency** results in **dwarfism**, characterized by slower development and short stature, however, the body parts stay in proportion and brain development and IQ are unaffected.
- **Gigantism** results from **GH over-secretion** during childhood, in which the bones are still capable of growth causing abnormal height increase, while **acromegaly** in adults causes bone thickness increase without lengthening.




- Somatotrophin releasing factor (SRF) is secreted from hypothalamus throughout life.
- When growth has mostly ceased after adolescence, the hormone continues to promote protein synthesis throughout the Body.
- **Under-secretion** leads to dwarfism and other symptoms related to lack of **thyroid and adrenal hormones.**

## THYROID STIMULATING HORMONE

- Thyrotrophin releasing factor (TRF) from the hypothalamus stimulates the synthesis and release of TSH from the anterior pituitary.
- TSH regulates the **endocrine function** of the **thyroid gland**, increasing the number of cells and its secretory activity.
- **Over-secretion** of TSH causes **hyperthyroidism** (excess thyroxin), and **under-secretion** causes **hypothyroidism** (lack of thyroxin).

**PTB**

- The release of **thyrotrophin releasing factor** from the hypothalamus is controlled by **thyroxine** levels in the blood.
- Low **thyroxine** levels increase **TSH** production and vice versa.
- **TRF** is secreted throughout life, especially during periods of rapid growth and development.
- It acts directly on **thyroid gland cells**, increasing their numbers and secretory activity.

## ADRENOCORTICOTROPHIC HORMONE (ACTH) (CORTICOTROPHIC HORMONE)

- The release of **corticotrophin-releasing factor** from the **hypothalamus** is controlled by **steroid levels** in the blood and by direct **nervous stimulation** due to **stress** (e.g., cold, heat, pain, infections).
- **Excess or deficiency** of ACTH results in disturbances of normal **adrenal functions**.
- ACTH acts on the **adrenal cortex**, stimulating the secretion of **corticosteroids** (cortisone and aldosterone), **glucocorticoids**, and **androgens**.
- **Cushing's disease** is caused by a **pituitary gland tumor** that **oversecretes ACTH**, overstimulating the adrenal cortex to increase **cortical production**.

## GONADOTROPHINS

- **Gonads** are the male and female sex organs (**testes/ovaries**).
- **Gonadotropins** are hormones that affect these organs, classifying them as **endocrine glands** because they secrete **sex hormones** (**follicle-stimulating hormone (FSH)** and **luteinizing hormone (LH)**).
- These hormones act upon the **reproductive system** and regulate its

**KPK**

- TSH release is regulated by the negative feedback of thyroxin acting on hypothalamus and anterior pituitary.

**BTB**

- TSH controls the secretion and development of thyroid gland.
- Low TSH level may be harmful for health, heart disease and osteoporosis may occur.
- While high TSH level in blood indicates hypothyroidism.

## FSH

Functions.

- In human females, FSH targets the ovary and triggers the maturation of one egg (sometimes more) per month.
- Its secretion is stimulated by GnRH from the hypothalamus.

## LH

- LH secretion is also controlled by gonadotropin-releasing hormone (GnRH).
- In females, an LH surge near mid-menstrual cycle stimulates the release of an egg from the Graafian follicle of the ovary.
- LH triggers the development of cells within the ruptured follicle to form the corpus luteum (glandular structure), which secretes progesterone to prepare the uterus for an embryo.
- LH is responsible for multiple births.
- In males, LH is also known as Interstitial Cell Stimulating Hormone (ICSH) and promotes the production of testosterone.
- Low secretion of both FSH and LH leads to delayed sexual maturation. GnRH deficiency may be congenital or acquired.
- The target site of LH is the ovary, where it triggers ovulation and the ovarian production of estrogen and progesterone.

## PROLACTIN HORMONE (PRL)

- PRL works in conjunction with estrogen, progesterone, and other hormones.
- It causes the enlargement of mammary glands and prepares them for milk production (lactation) after birth, stimulating mothers to care for their young.
- During the menstrual cycle, milk is not produced or secreted because prolactin levels in the blood are very low.
- PRL inhibits the menstrual cycle in lactating women.



**PTB**

- These hormones include FSH, LH (also called ICSH in males), and prolactin (sometimes inappropriately called luteotrophic hormone (LTH)).
- FSH and LH/ICSH share a common hypothalamic releasing factor.
- Prolactin is continuously produced by the pituitary and is inhibited by prolactin-inhibiting factor (PIH) from the hypothalamus. Prolactin stimulates milk production and acts with LH as described above.
- FSH in females stimulates follicle development and oestrogen secretion from the ovaries; in males, it stimulates the development of the germinal epithelium of the testes and sperm production.
- LH works with FSH to stimulate oestrogen secretion and the rupture of mature follicles to release an egg (ovum).
- LH also causes the lutenization ("turning yellow") of the ruptured follicle and acts synergistically with prolactin to maintain the corpus luteum and its secretion of progesterone.
- ICSH in males stimulates the interstitial cells of the testes to secrete

testosterone.

## MEDIAN LOBE

- In humans, the median lobe of the pituitary is not prominent. It is a **thin layer of cells** between the anterior and posterior pituitary.
- It produces **melanocyte-stimulating hormone** (MSH), regulated by **hypothalamic MSH inhibitory hormone**.
- MSH levels increase during **pregnancy**, stimulating **melanin** production by **melanocytes** in **skin and hair**.
- The median lobe is the **smallest** in humans.
- **External light** governs MSH secretion. Increased MSH during pregnancy darkens the skin.
- **Excess MSH** is secreted in **Addison's disease**, a symptom of which is **skin darkening**.

## POSTERIOR LOBE

- The posterior pituitary is **not glandular** and does not synthesize any hormones.
- It is largely composed of **axons** from **neurosecretory cells** of the **hypothalamus**.
- The posterior pituitary stores **antidiuretic hormone (ADH or vasopressin)** and **oxytocin**, releasing them in response to **nerve impulses** from the hypothalamus.

### ANTI-DIURETIC HORMONE OR VASOPRESSIN

- ADH secretion is triggered by a decrease in **blood pressure**, **blood volume**, and **osmotic pressure**, detected by osmoreceptors in the **hypothalamus**.
- **External sensory stimuli** also influence **hypothalamic neurosecretory cells**.
- Increased **ADH** levels enhance **water reabsorption** in the distal parts of the **nephron**.
- A deficiency of **ADH** leads to **diabetes insipidus**, characterized by large quantities of **dilute urine** and intense **thirst**.

**FTB**

- Under conditions like severe **blood loss**, exceptionally large amounts of **ADH** are released, causing a rise in **blood pressure**.
- The alternative name **vasopressin** reflects its role in **vasoconstriction** and **blood pressure regulation**.

### OXYTOCIN (OXYTOCIA=CHILD BIRTH)

- Its release is stimulated by **distension of cervix**, decrease in **progesterone** levels in blood, and **neural stimuli** during **childbirth** and suckling.
- Primary action is on **smooth muscle**, particularly in the **uterus** during childbirth, and also causes **milk ejection** from mammary glands.
- The **letdown reflex** (milk ejection reflex) is triggered by this hormone.

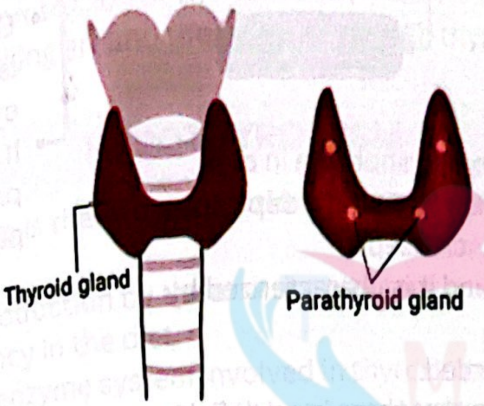
**BTB**

- **ADH regulates blood volume by controlling water reabsorption in the kidneys.**
- **Osmoreceptors in the hypothalamus detect high blood solute concentration, triggering ADH production by neurosecretory cells. ADH is transported to the posterior pituitary and released into the bloodstream.**
- ADH binds to target cells in the collecting ducts of nephrons, increasing water permeability and concentrating urine.
- Blood volume increases, normalizing solute concentration.
- ADH also acts on smooth muscles around **arterioles**, raising blood pressure.
- **Alcohol suppresses ADH release**, that is why excessive drinking leads to the production of excessive quantities of urine and eventually to dehydration.

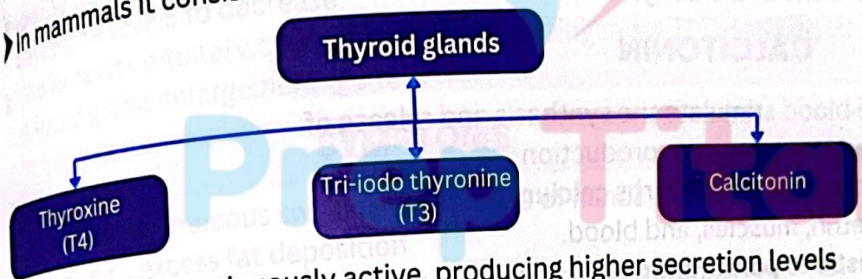
FTB

- Released during childbirth and in nursing women. During birth, it is released in waves, resulting in labor contractions.
- Over-secretion causes rupturing of the uterine wall, while under-secretion inhibits normal labor.
- In lactating women, suckling triggers the release of oxytocin.
- During feeding, it causes the dilation of milk ducts in the mammary glands, promoting milk ejection.

## TYHROID GLAND




- In mammals it consists of two lobes situated **below the larynx**.




- The thyroid is continuously active, producing higher secretion levels during **rapid growth**, **sexual maturation**, and **stress** situations like cold and hunger.
- **Thyroxine ($T_4$)** and **Tri-iodothyronine ($T_3$)** are the primary hormones, acting similarly by stimulating the **basal metabolic rate**, **glucose breakdown**, **heat release**, and **ATP generation**.
- They work with **somatotropin** to promote **growth** and directly influence **brain cell differentiation**.
- In **amphibians**, these hormones facilitate **metamorphosis**. Thyroid **deficiency** prevents tadpoles from developing into frogs, resulting in oversized tadpoles.

### GRAVES DISEASE

- **Excess thyroxine** produces a condition called Graves' disease, with exophthalmic goiter and increase in the basal metabolic rate.
- This can lead to cardiac failure if prolonged.
- The cause of Graves' disease is the production of an **abnormal body protein** which continuously stimulates the thyroid to excessive secretion.

### DEFICIENCY OF HORMONE

- If **congenitally deficient**, the lack of thyroxine causes **cretinism**.

**KPK**

- **Diuresis** means urine production. **Antidiuretic** substances inhibit urine formation.

**BTB**

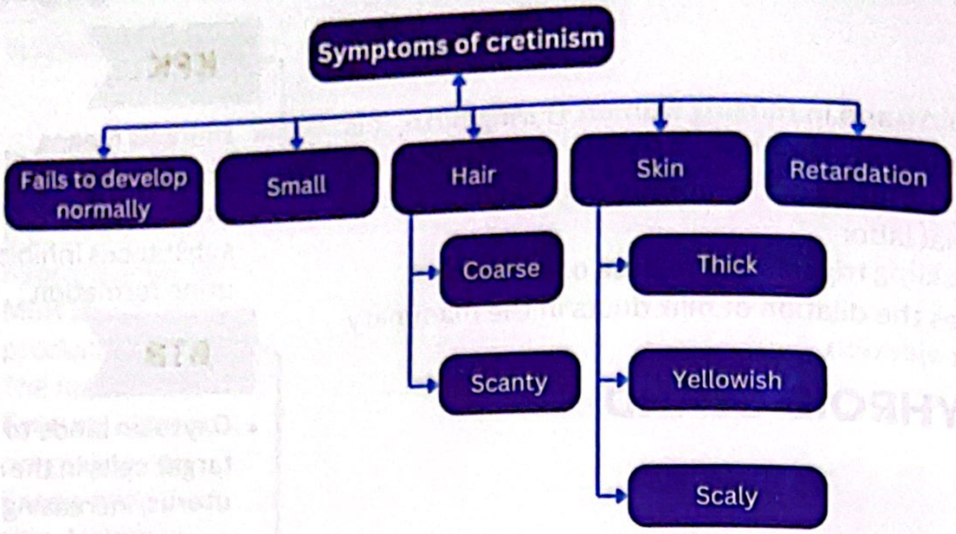
- **Oxytocin** binds to target cells in the **uterus**, increasing contractions. It is also used artificially to induce **labor**.
- In males, it helps eject **semen** during copulation.
- Infant suckling triggers large amounts of oxytocin, aiding in nursing and contracting the uterus to normal size.

**KPK**

- The level of thyroxin in the blood regulates hormone secretion from the thyroid gland via **negative feedback** involving the hypothalamus and anterior pituitary.

**BTB**

- Butterfly-shaped and both lobes are connected by a bridge of thyroid tissue known as **isthmus**.
- Triiodothyronine or T3 (about **10%** but four times more




- They also fail to develop sexually.
- **Deficiency later in life**, perhaps due to iodine shortage in diet, produces swelling of the neck (goiter) and may lead to deposition of excess fat as a result of which weight is increased.
- The condition is known as **myxoedema**, and it is characterized by puffiness of hands and skin.
- All bodily and mental processes are retarded.
- Table salt with iodine is recommended so that there is no deficiency of iodine and thus of thyroxine in the body.

## CALCITONIN

- **High $Ca^{2+}$** levels in the blood stimulate the synthesis and release of **calcitonin**; low $Ca^{2+}$ levels suppress its production.
- Excess or deficiency of **calcitonin** disturbs **calcium metabolism**, affecting nerves, skeleton, muscles, and blood.
- **Calcitonin** is antagonistic to **parathormone**.

**FTB**

- The **thyroid gland** consists of two **lobes** located on either side of the **trachea**, below the **larynx**.
- **$T_3$ (Tri-iodothyronine)** contains three iodine atoms, and **$T_4$ (thyroxine)** contains four, hence their names.
- **TSH** from the **anterior pituitary** stimulates the production and release of **$T_3$** and **$T_4$**.

## PHYSIOLOGICAL EFFECTS

- These hormones show a variety of physiological effects.
- Enhance **cholesterol synthesis** in the liver.
- Promote **nervous system development** in fetuses and infants.
- Act on **muscles** for development and functioning.
- Promote **growth and maturation** of the skeleton.
- Ensure normal **gastrointestinal motility**.

## HYPERTHYROIDISM

- **Hyperthyroidism** refers to the **overactivity of the thyroid**, primarily caused by **Graves' disease**, an autoimmune disorder.

potent than T4).
- It is more active in mammals.
- Tetra-iodothyronine or T4 (about 90% thus major hormone also called thyroxin).
- The duration of action of T4 is four times more than T3.
- Exophthalmic goiter is called bulging eyes.
- It may result in profuse perspiration.

- In **Graves' disease**, the serum contains **abnormal antibodies** that mimic TSH, continuously stimulating **thyroxin ($T_4$)** and **tri-iodothyronine ($T_3$)** release.
- **Symptoms** include:
- High metabolic rate
- Rapid and irregular heartbeat
- Nervousness
- Increased ventilation rate
- Increased body temperature
- Sweating
- Weight loss despite adequate food intake
- **Exophthalmia** (protrusion of the eyeballs), a classic symptom resulting from tissue swelling around the eyes due to high thyroxin levels

## HYPOTHYROIDISM

- Hypothyroidism is the **undersecretion of thyroxin ($T_4$)**, which may result from:
- Lack of TSH production by the anterior pituitary
- Iodine deficiency in the diet
- Failure of the enzyme system involved in thyroxin production
- Iodine deficiency impedes thyroid hormone synthesis, causing thyroxine levels to decrease.
- The anterior pituitary compensates by secreting more TSH, leading to thyroid gland enlargement (goiter).

### SYMPTOMS

- **Myxoedema** ("mucous swelling"): puffiness of hands and skin, weight gain due to excess fat deposition
- **Lethargy** and **mental sluggishness** (not mental retardation)
- **Cold intolerance**
- **Low pulse rate** and **low body temperature**
- **Puffy eyes, thick and dry skin, hair loss** from the scalp and eyebrows
- **Constipation**
- Delayed physical growth, disproportionate body size, delayed bone maturation and puberty, infertility
- **Enlarged thyroid gland (goiter)**, more common in iodine-deficient regions
- **Goitre** is more common in **mountainous areas** where iodine is scarce in the soil or water.
- Thus, **iodized table** salt is recommended.
- The thyroid gland works hard to produce a sufficient amount of **thyroxin**.
- **Goitre** may lead to **excess fat deposition** and **weight increases**.
- **Congenital deficiency** of thyroxin causes **cretinism (dwarf like condition)**, characterized by stunted growth, mental retardation, coarse facial features, coarse scanty hair, and retarded sexual development.
- **Myxoedema** results from severe hypothyroidism and is marked by brittleness of hair and nails, intolerance to cold, low pulse rate, and low body temperature.

- *Prevention: Use of **Iodized table salt** to avoid iodine and thus thyroxine deficiency.*

## CALCITONIN

- **Calcitonin** increases **calcium deposition** in the **bone matrix** and plays a minor but direct role in controlling extracellular $Ca^{2+}$ levels.
- It inhibits **$Ca^{2+}$ absorption** by the **intestine** and decreases its **reabsorption** in **kidney tubules**, promoting **urinary excretion**.
- **Calcitonin** is crucial in **childhood**, when the skeleton grows rapidly, and bones change dramatically in **mass**, **size**, and **shape**.
- Deficiency prevents **$Ca^{2+}$** deposition in bones, causing high blood **$Ca^{2+}$** levels that disturb muscle and **nervous system** function and may lead to **kidney stones**.
- Additionally, **Calcitonin** inhibits **potassium ion** reabsorption in **kidney tubules**.

# PARATYHROID GLAND

- In humans, there are four **parathyroid glands** located on the **thyroid gland**.
- They are small, light-colored masses protruding from the posterior surface of the thyroid.
- **Parathormone** is the main hormone controlling the **calcium balance** in the blood.
- Its release is triggered by low blood $Ca^{2+}$ levels and inhibited by high blood calcium levels. **Parathormone** acts antagonistically to **calcitonin**.

## OVER SECRETION OF PARATHORMONE

- Usually caused by a parathyroid gland **tumour**.
- Releases calcium from bones, causing bones to deform, soften, and fracture spontaneously.
- **Hypercalcemia** depresses the nervous system and causes muscle weakness.
- Leads to progressive demineralization of bones like **rickets**.
- Excess calcium salts precipitate in the kidneys, causing **stone formation**. Both conditions can be fatal.

## UNDER SECRETION OF PARATHORMONE

- Causes **hypocalcemia**, increasing neuron excitability.
- Can lead to **tetany**, where muscles remain contracted. If untreated, it can be fatal.
- In humans, the glands are embedded in the posterior part of the lateral lobes of the thyroid.

# PANCREAS

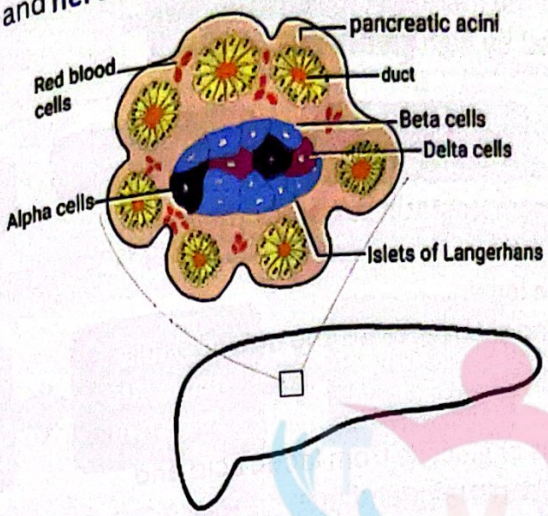
- The production of **insulin** and **glucagon** is controlled by pituitary hormones **STH** and **ACTH** and directly responds to blood glucose levels.
- The islets contain large number of **beta cells** for **insulin** production.
- A smaller number of **alpha cells** secrete **glucagon**.
- **Insulin** lowers blood glucose by increasing **glycogen synthesis** and

**BTB**

- Parathyroid glands are oval in shape.
- **Parathormone** regulates calcium and phosphorus levels in the blood and influences gene activation.
- Over-secretion increases blood calcium levels and lowers phosphate concentration.
- Causes skeletal weakness similar to **rickets**.
- Nerves and muscles do not respond well to stimuli due to movement of $Ca^{2+}$ to extracellular fluids.
- Increases reabsorption of $Ca^{2+}$ by the kidneys, causing massive kidney stone formation.
- These conditions may be fatal; removal of glands causes death.
- **Parathormone** stimulates osteoclasts to reabsorb bone mineral, liberating calcium into blood.
- It stimulates calcium absorption in the small intestine and its reabsorption in the kidney tubules.

cellular glucose utilization.

- It also stimulates the conversion of **glucose** into **lipids** and **proteins**, reducing glucose levels.
- Insulin inhibits the hydrolysis of **glycogen** in the liver and muscles.
- Failure to produce **insulin** leads to **diabetes mellitus**.
- Symptoms include **high blood sugar**, **sugar in urine**, disturbed **osmotic equilibrium**, and **nervous system derangement**.




- **Toxic metabolites from fat** (which need 'glucose energy' for their oxidation) also accumulate and are only lost from the kidney with valuable metal cations.
- The body becomes **dehydrated**. If excess insulin is produced the utilization of sugar is too great and its level falls in the blood (hypoglycemia) which upsets nerve and muscle functioning.
- **Glucagon** antagonizes **insulin**, increasing blood glucose levels as a **hyperglycemic agent**.
- It promotes the breakdown of **glycogen** to **glucose** in the liver and muscles.
- It also increases the rate of **fat breakdown**.
- **Glucagon** abnormalities are rare endocrine disorders.
- **Alpha cell tumors** cause excess **glucagon** secretion, leading to **high blood glucose** levels.
- This excess **glucagon** damages **beta cells**, causing the effects mentioned above.



### FTB

- Pancreas is composed of **two types of tissues**.
- **Exocrine tissue** produces and secretes digestive juice.
- **Endocrine tissues** are distributed in the form of patches in the pancreas and these patches are called **Islets of Langerhans**.
- Pancreatic **acinar cells** are the **functional unit** of the exocrine pancreas.
- They synthesize and secrete inactive digestive enzymes into the lumen of acinus.
- The Islets of Langerhans secrete **two hormones** insulin and glucagon.
- These cells respond directly to the level of blood glucose.
- Insulin is secreted when the level of blood sugar rises, such as right after a meal.

### KPK

- The pancreas is a dual-function gland, serving as both an **exocrine** and **endocrine** gland.
- The bulk is **exocrine**, formed by **acinar cells** synthesizing **pancreatic juice** rich in **digestive enzymes**.
- **Pancreatic juice** is delivered to the **duodenum** via the **pancreatic duct** during food **digestion**.
- The human pancreas has about **one million islets** scattered among the acinar cells.
- Each islet is a small mass of cells with two major types of cells: glucagon producing cells and insulin producing beta cells.

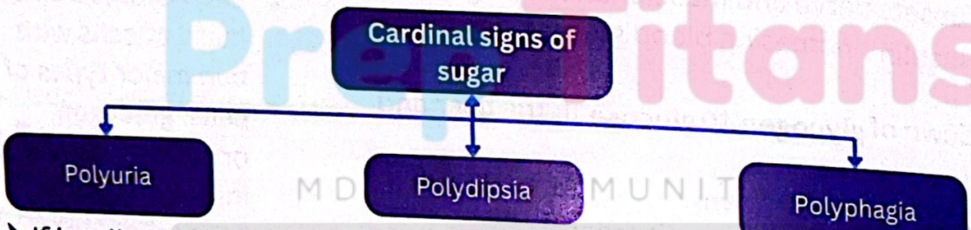
### BTB

- Beta cells are about **60%** and alpha cells are about **25%**.
- Insulin is made of **51** amino acids.
- It facilitates glucose transport across plasma membrane.
- It stimulates the uptake of glucose by adipose tissue (fat storing cells).
- Glucagon is made of **29** amino acids.

- Its overall effect is to reduce blood glucose level to the normal level by increasing the rate of glucose uptake by most body cells especially skeletal muscles and fat cells.
- It promotes glycogenesis (conversion of glucose to glycogen), increases the use of glucose in cellular respiration, promotes the conversion of excess glucose to fats and inhibits gluconeogenesis (glucose synthesis).
- The under secretion of insulin leads to the metabolic disease known as diabetes mellitus which is characterized by high glucose levels in the blood and urine.
- Glucagon is released by a cell when blood glucose level is low.
- The sympathetic nervous system also stimulates its secretion.
- High blood glucose levels, insulin and somatostatin suppress their secretion.
- Its role is to increase the blood glucose level.
- It acts antagonistically to the insulin and thus reverses the activities performed by insulin.
- It promotes glycogenolysis.
- It promotes gluconeogenesis, synthesis of glucose from lactic acid and other non-carbohydrate compounds like proteins and fats.
- Promotes release of glucose to the blood by liver cells, which causes blood glucose levels to rise.

## INSULIN

- Increases the rate of uptake of amino acids into the cells and the rate of protein synthesis.




- If insulin is deficient or is hypoactive, blood glucose level after meal remains high (hyperglycemia).
- Kidneys cannot reabsorb such high volume of glucose from the filtrate and excess of glucose begins to be lost from the body in the urine (glycosuria).
- This metabolic disease is known as diabetes mellitus.

## POLYURIA

A condition in which an abnormally large volume of urine is produced.

## POLYDIPSIA

A condition of excessive thirst.

## POLYPHAGIA

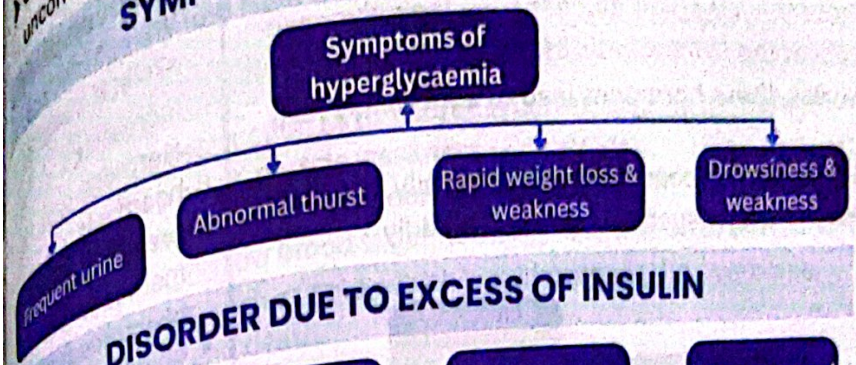
A condition of excessive hunger ingestion of food.

- Low blood glucose level causes breakdown of the muscle tissue, loss of weight and tiredness.
- If untreated diabetes finally leads to the disruption of the heart activity and oxygen transport, and severe depression of the nervous

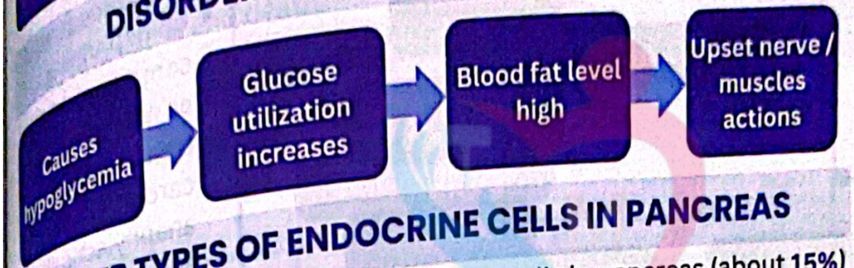
system leads to coma and death.

- Hypersecretion (a rare disorder) of insulin results in hypoglycemia.
- Other effects include hunger, sweating, irritability, double vision, unconsciousness, and even death.

## SYMPTOMS OF HYPERGLYCAEMIA

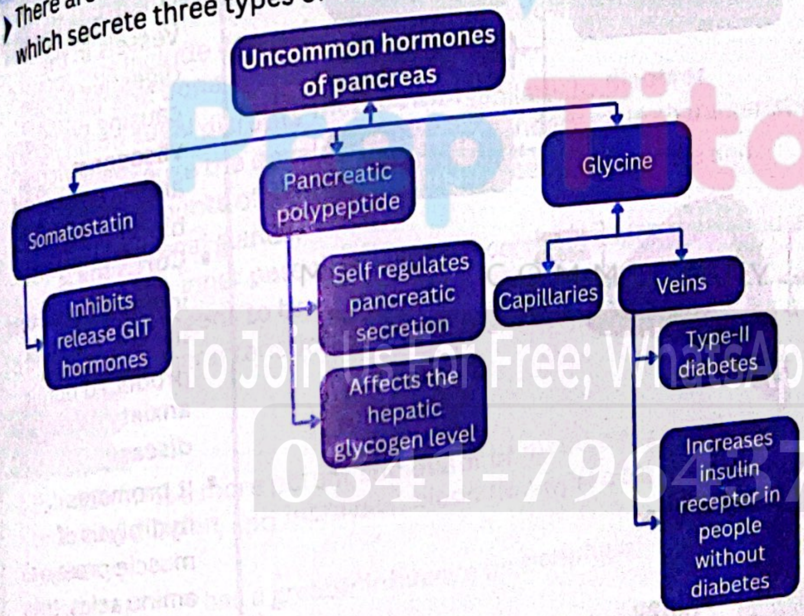



## DISORDER DUE TO EXCESS OF INSULIN




## OTHER TYPES OF ENDOCRINE CELLS IN PANCREAS

- There are three other types of endocrine cells in pancreas (about **15%**) which secrete three types of hormones.




- Glycine is used as supplement by type-II diabetes patients.

## ADRENAL GLAND

**(ad: beside, renal: kidney)**

- A pair of **adrenal glands** is located on top of each **kidney**. The outer layer is the **adrenal cortex**, and the inner layer is the **adrenal medulla**.
- **Adrenal cortex** is the outer reddish-brown portion.
- **Adrenal medulla** is the inner greyish portion.

### TITLE

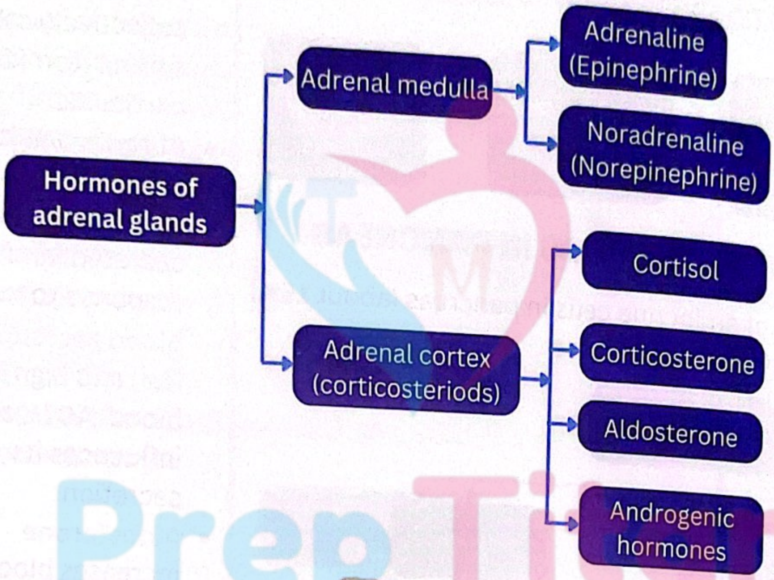
- Both adrenaline and noradrenaline are secreted in stressful

**KPK**

- The **adrenal gland** produces many steroid hormones, collectively called **corticosteroids** or **corticoids**.
- **Aldosterone** is the chief **mineralocorticoid**, secreted in response to **low blood pressure**, low $Na^+$, and high $K^+$ in blood. **ACTH** also influences its secretion.
- **Aldosterone** increases blood $Na^+$ levels by acting on **kidney tubules** to enhance **sodium** and **water reabsorption**.
- The adrenal **medulla** consists of modified ganglionic sympathetic neurons that synthesize **epinephrine** and **norepinephrine**, which exert similar effects.
- Epinephrine is used clinically as a **heart stimulant** and to **dilate the bronchioles** during acute asthmatic attacks.

situations.

- Essentially **adrenaline dilates blood vessels** in certain parts of the body such as the skeletal muscles and increases the heart's output.
- Noradrenaline constricts blood vessels but again only in certain areas, such as the gut, so the effects of the two hormones are synergistic in raising blood pressure.
- These hormones promote the release of **glucose** from **liver glycogen** and reinforce the effects of the **sympathetic system**.
- Rarely found, but in excess, these hormones lead to abnormally high blood pressures.
- In rats whose adrenal medulla has been removed surgically, the ability to withstand any stress situation - such as cold - is markedly diminished.







## CORTICAL HORMONES

- The adrenal cortex is always active but especially so during **shock**, **stress**, or **infections**.

**BTB**

- Epinephrine di[...] blood vessels [...] **brain, heart,** and **skeletal muscles**, increasing alertness, heartbeat, breathing rate, [...] metabolic rate [...] overcome stress.
- **Epinephrine** is sometimes injected as emergency treatment for cardiac arrest, anaphylactic shock, and acute asthma.
- **Norepinephrine** constricts blood vessels in the digestive system, causing peripheral vasoconstriction and sustaining blood pressure.
- **Cortisone** is involved in **glucose metabolism** and is produced during **anxiety**, **fever**, and **disease**.
- It promotes hydrolysis of muscle protein to amino acids, then amino acids to glucose, and neutralizes inflammatory responses, reducing pain and swelling in arthritis.
- **Cortisone** favors metabolism of **fatty acids** over **glucose**, antagonistic to **insulin**.
- **Aldosterone**

- **Cortisol** (a **glucocorticoid**) increases **blood glucose** levels by promoting **protein production** and antagonizing **insulin**.
- **Corticosterone** acts as both a **glucocorticoid** and a **mineralocorticoid**, increasing **blood glucose** and regulating **mineral ion balance**.
- **Aldosterone** is the principal **mineralocorticoid**, conserving **$Na^+$ ions** by preventing their loss from the **kidney tubules**.

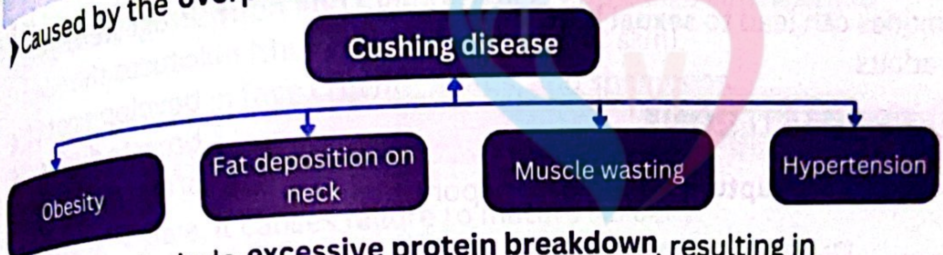
promotes renal absorption of sodium and renal excretion of potassium, maintaining blood volume and blood pressure.

## ADDISON'S DISEASE

- Caused by the destruction of the **adrenal cortex**, leading to **metabolic disturbances** such as **muscle weakness** and **salt loss**.
- Results from lower secretion of **corticosteroids**.
- Symptoms include **low blood sugar**, **lethargy**, and a **bronze skin tone**.
- **Stress situations**, such as cold, which would normally be overcome, lead to collapse and death.

## CUSHING'S DISEASE

- Caused by the **overproduction of cortisol**.




- Symptoms include **excessive protein breakdown**, resulting in **muscular and bone weakness**.
- **High blood sugar** disrupts **metabolism** similarly to **diabetes**.
- **Androgens** cause the development of **secondary male characteristics**.
- Very small amounts of androgens are secreted in both male and female by adrenal glands.
- A tumor on the inner part of the adrenal cortex in a female can cause excess of androgens to be produced and thus the development of certain male characteristics. Such cases are very rare.

**FTB**

- **Epinephrine** is a more potent stimulator of **metabolic activities**, **bronchial dilation**, and **increased blood flow** to **skeletal muscles** and the **heart**.
- **Norepinephrine** has a greater influence on **peripheral vasoconstriction**.
- The net effect of both hormones is a **rise in blood pressure**.
- **Oversecretion** may cause **hypertension** and **aggressive behavior**; **undersecretion** impairs the ability to handle **emergencies**.
- The two major hormone types from the **adrenal cortex** are:
- **Glucocorticoids** (e.g., **cortisone**) regulate **blood glucose** levels.
- **Mineralocorticoids** (e.g., **aldosterone**) regulate **mineral levels** in the blood.
- Both are produced under the influence of **ACTH**.
- The major site of **testosterone** secretion is the **testes**.

## GONADS

- **Gonads** are specialized endocrine glands that produce **hormones** and

gametes.

- **Female gonads** are **ovaries**, while **male gonads** are **testes**.

# OVARY

The human female contains two ovaries in the **abdominal cavities**.

## ESTROGEN

- Estrogen is secreted by **ripening follicles** and, in many species, by **interstitial cells** of the ovary, initiated by **FSH** from the pituitary.
- Estrogens develop **secondary sexual characteristics** in females, thicken the **uterine wall**, and exert **positive feedback** during the menstrual cycle or oestrous, causing a sharp rise in **LH** output by the pituitary.
- They aid in healing and repairing the **uterine wall** post-menstruation.
- Under estrogen influence, some **uterine wall cells** become glandular, secreting **proteinaceous secretions** absorbed by the **embryo** during early development.
- **Deficiency** of sex hormones can lead to **sexual immaturity** in the young and **sterility** in adults.

**KPK**

- Acting with progesterone, estrogens promote breast development and cyclic changes in the uterine mucosa in the menstrual cycle.
- Progesterone causes the development of breasts during pregnancy.

## PROGESTERONE

- Progesterone is produced by the **ruptured follicle** in response to **LH** from the pituitary.
- It **inhibits further FSH** secretion, preventing further follicle ripening.
- Affects the **uterus**, causing further **thickening** and **vascularization** of its wall, and prepares the female body for pregnancy.
- **Suppresses ovulation**, making it a major component of **birth control pills**.

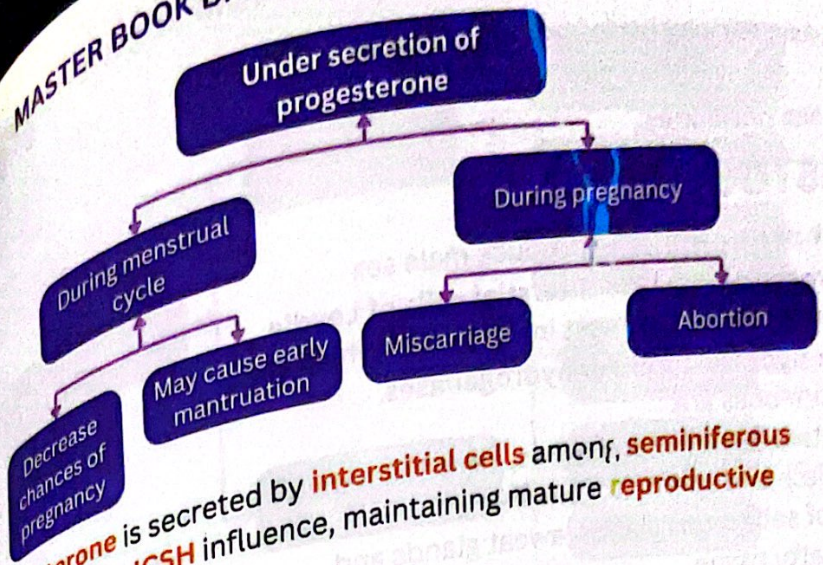
# TESTES

- **Testes** contain coiled **seminiferous tubules** where **spermatozoa** develop.
- **Interstitial cells** between tubules produce **testosterone** and **17β-hydroxy testosterones**.
- After the initiation of development, the sex organs in the foetus produce them, and their level rises fairly consistently until puberty.
- After puberty the supply of LH (ICSH), and therefore, the level of testosterone, remains constant.
- In the foetus, it initiates the development of the sex organs.
- At puberty it brings about development of the male secondary characteristics and promotes the sex drive.
- The **castrated male** fails to develop secondary sexual characteristics and his body tends more towards the form of the immature female.



**FTB**

- **Estrogen** is secreted by the **Graafian follicle** under **FSH** stimulation, but **estrogen** negatively feedback on **FSH**.
- **Estrogen** secretion begins at **puberty**; over-secretion may cause **uterine fibroids** (abnormal growth) and **polycystic ovaries**.
- **Progesterone** is produced and released from the **placenta** during **pregnancy**.



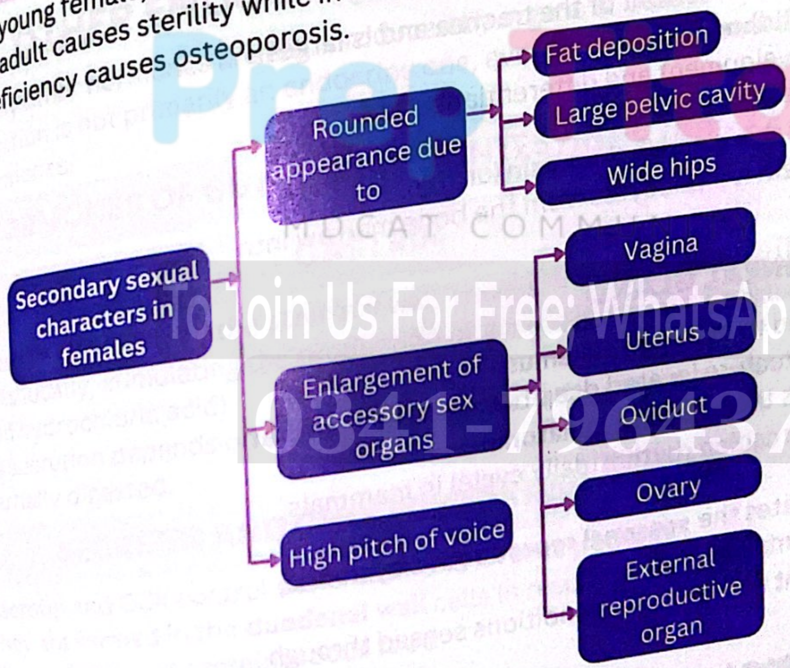

- **Testosterone** is secreted by **interstitial cells** among **seminiferous tubules** under **ICSH** influence, maintaining mature **reproductive organs** in adult males.

## ESTROGEN

- Three types: **estrone, estriol**, and **estradiol**, are similar in function.
- At **puberty**, they develop **secondary sexual characteristics**, aid in **pregnancy conception and maintenance**, and cause **softness and smoothness of skin** (thus females have softer skin).
- Estrogen is used in **face creams, soaps**, and **shampoos**.

## DISORDERS DUE TO DEFICIENCY OF ESTROGEN

- In young female, it causes failure to mature sexually.
- In adult causes sterility while in old women after menopause, its deficiency causes osteoporosis.






## PROGESTERONE

- The **ruptured follicle** becomes **corpus luteum** which secretes progesterone.
- Regulates **secretion of gonadotropin** from anterior pituitary.

## POLYCYSTIC OVARY SYNDROME

- Ovarian disorder with numerous small **follicle** collections.

- *Disturbs regular* **egg release**, causing prolonged and irregular **menstrual periods.**
- Increases levels of **male sex hormones.**

## TESTOSTERONE

- *The testis in the presence of* **FSH** and **ISCH** produce male sex hormones known as **androgens,** from their **interstial cells of Leydig.**
- *There are many types of androgens, the most important of which are* **testosterone** and **17 beta-hydroxysteroid dehydrogenases.**
- The functions of these hormones are:
- Secondary sexual characters (beard, moustaches, axillary and pubic hair, voice become low pitch and spermatogenesis).
- They increase secretion of sebaceous glands, sweat glands and increase sub cutaneous fatty tissue.
- Increase metabolic activities in general.
- Inhibit formation of female genital organs in fetus.
- Increase Red Blood Cells (RBCs) production and thickness of bones.

## SOME OTHER GLANDS AND THEIR HORMONES

### TYMUS GLAND

- The **thymus gland** is a lobular endocrine gland located in the upper chest behind the sternum.
- It consists of two lobes that join in front of the trachea and is largest and more active during **childhood**.
- It is responsible for the development and differentiation of T-**lymphocytes** before they exit the thymus.
- The hormone produced by this gland is **thymosin** (or **thymin**).
- **Thymosin** transforms certain lymphocytes from the bone marrow into **T lymphocytes**.

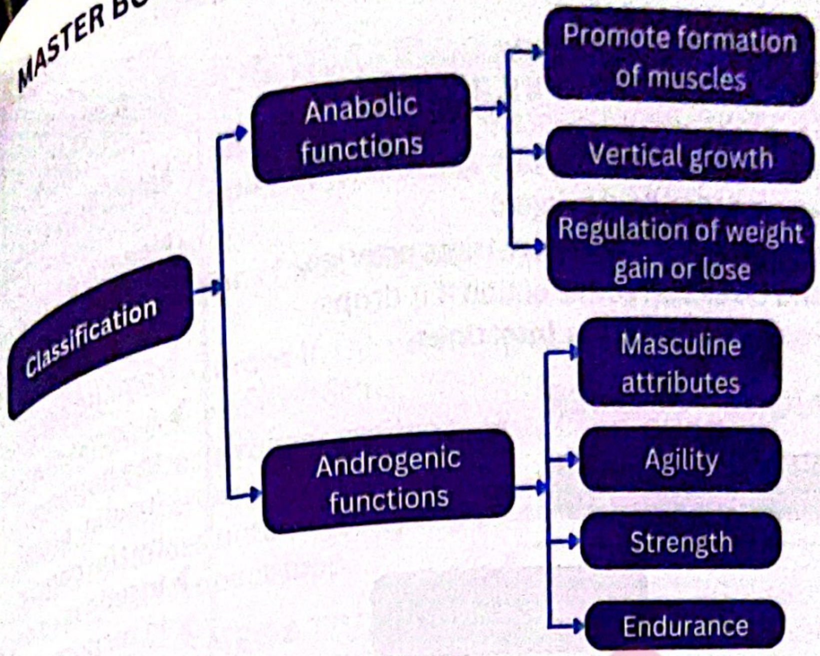


### PINEAL GLAND

- The pineal gland is attached to the **hypothalamus**.
- It is a tiny, cone-shaped structure located deep between the **cerebral hemispheres** and produces the hormone **melatonin**.
- **Melatonin** regulates the **circadian rhythm** (daily cycle) in mammals, controlled by the eyes.
- In many mammals, it regulates the **seasonal reproductive cycle** and the **sleep-wake cycle** in humans.
- It responds to external **light and darkness** conditions sensed through the eyes.

## ROLE OF ARTIFICIALLY SYNTHESIZED STEROIDS IN SPORTS

- **Steroids** are artificial substances developed to mimic the effects of **testosterone**.
- It can be classified as either **anabolic** or **androgenic**




- These drugs help sportsmen become **bigger**, **stronger**, **more agile**, and thus more competitive.
- However, artificial steroid use carries many severe **health risks**.
- Major medical problems associated with steroids include a weakened **immune system**, **liver disease**, **kidney disease**, **high blood pressure**, **high cholesterol**, increased risk for **heart disease**, **blood clots**, **strokes**, **tissue damage**, and **cancer**.

## OTHER ENDOCRINE TISSUES/CELLS

- Many other hormones are also produced by organs or tissues whose function is not primarily an endocrine one, even neurons also secrete hormones.

### HORMONES OF GUT (GASTRO-INTESTINAL TRACT)



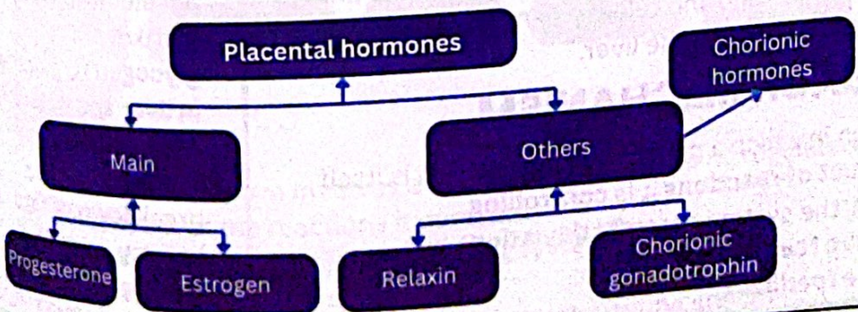
#### GASTRIN



- **Gastrin**, produced by the **stomach wall**, travels in the bloodstream but acts locally, stimulating the production of **gastric juice** (pepsinogen and hydrochloric acid).
- Its secretion depends on **proteinaceous** food in the stomach when it is partially digested.

#### SECRETIN AND CHOLECYTOKININ (CCK)

- Secretin and CCK control **pancreatic** and **liver** secretions.
- They are formed in the **duodenal wall** cells in response to **acidic chyme**, **fatty**, and **proteinaceous food**.

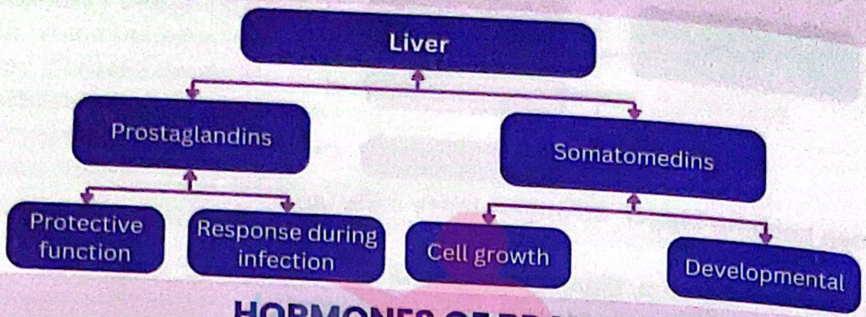


- All of these facilitate in **pregnancy** and **birth**.

## HORMONES SECRETED FROM KIDNEYS

- **Erythropoietin** increases **red blood cell** production and is released in response to **bleeding** or high altitudes (low oxygen).
- **Renin** (also called **urotensin** and **angiotensin**) constricts arteries, monitors **blood pressure**, and takes corrective action if it drops.
- **Calcitriol** promotes **calcium absorption** in the **intestines**.

## HORMONES OF LIVER




## HORMONES OF BRAIN

- **Enkephalins** and **endorphins** bind to **pain receptors** and block sensation.
- **Enkephalins** are found in the **thalamus** and parts of the **spinal cord**, while **endorphins** are located in the **pituitary gland**, other brain regions, or distributed throughout the **nervous system**.

## HORMONE OF HEART

- The **heart** secretes **atrial natriuretic hormone**, which increases **sodium excretion** and lowers **blood pressure**.



## ADIPOSE TISSUES

- Secretes a hormone **leptin**, which reduces appetite.

**PTB**



## GASTRIN

- Gastrin is the hormone produced by mucosa of the pyloric region of the stomach.

## SECRETIN

- It is produced from the duodenum when acid food touches its lining.
- It affects the pancreas to produce and release pancreatic juice and affects the rate of bile production in the liver.

# FEEDBACK MECHANISM

- It is a type of interaction in which a controlling mechanism is itself controlled by the **product of reactions** it is **controlling**.
- Upon receiving a **signal**, the system **corrects deviations** by:
- **Depressing** with **negative feedback**
- **Enhancing** with **positive feedback**

**KPK**

**NEGATIVE FEEDBACK**

**Negative feedback** stabilizes a system by correcting deviations from the set point.

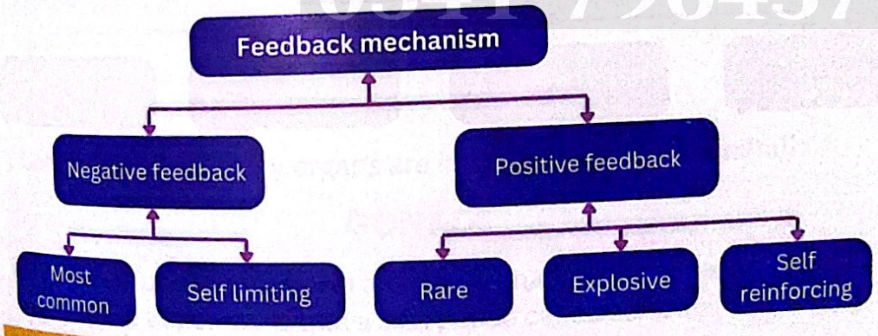
- A prime example is the hormone **insulin**, produced by the **pancreas**.
- **Insulin** is released in response to **glucose** consumption.
- When blood glucose levels rise, the pancreas detects this increase and secretes **insulin** into the blood.
- **Insulin** enhances glucose uptake in target cells, lowering blood glucose levels.
- The pancreas senses the decreased glucose levels and stops secreting **insulin**.
- If blood glucose falls below normal, **insulin** secretion is inhibited.
- Simultaneously, the pancreas's **alpha cells** secrete **glucagon**.
- **Glucagon** accelerates the breakdown of **glycogen** to glucose in liver and muscle cells.
- It promotes the breakdown of fats to fatty acids and glycerol in adipose tissue, releasing

## POSITIVE FEEDBACK

- In positive feedback, an end product **accelerates its own production.**
- These responses are **non-homeostatic** and **rare** in healthy individuals.
- ***Example: Childbirth***
- *Early* **Labor contractions** force the baby's head against the **cervix** to *dilate.*
- *Stretch-receptive* **neurons** in the cervix signal the **hypothalamus,** *triggering* the release of **oxytocin.**
- *Oxytocin* stimulates **stronger uterine contractions,** increasing *pressure* on the cervix.
- *This* cycle continues until the **baby and placenta are expelled,** *terminating* the feedback loop.

## NEGATIVE FEEDBACK

- In negative feedback, end products **reverse the direction of change,** maintaining **homeostasis.**
- In this system an endocrine gland is sensitive either to the concentration of a substance it regulates or to the concentration of a product from a process it controls.
- **Example: Blood Glucose Regulation**
- **High blood glucose:**
- Beta (β) cells in the islets of Langerhans release insulin.
- Insulin makes cell membranes more permeable to glucose by activating transport proteins.
- Glucose enters cells and is converted to glycogen.
- Blood glucose levels decrease.
- **Low blood glucose:**
- Alpha (α) cells in the islets of Langerhans secrete glucagon.
- Glucagon binds to receptors on cell surfaces, activating enzymes that convert glycogen to glucose.
- Glucose is released into the blood, raising blood glucose levels.
- Through these mechanisms, negative feedback maintains blood glucose within a normal range.




**PTB**

- A **feedback mechanism** involves a controlling system being regulated by the product of the reactions it controls.
- For proper body functions, two opposing systems are needed: **accelerators** and **inhibitors.**
- If one **hormone** promotes a reaction, another **hormone** checks it.

them into the blood.

- **Glucagon** also stimulates liver cells to synthesize and release glucose into the blood.
- These actions collectively restore blood glucose levels to normal.

### POSITIVE FEEDBACK

- **Positive feedback** facilitates **childbirth** through the hormone **oxytocin**, which stimulates and enhances labor contractions.
- As the baby moves toward the birth canal, it presses against **pressure receptors** in the uterine muscles.
- These receptors trigger the release of **oxytocin** from the **pituitary gland.**
- **Oxytocin** binds to receptors in the uterine muscles, increasing muscular tension and further stimulating the pressure receptors.
- This loop continues until the baby is born, relieving pressure and stopping **oxytocin** release, thus ending contractions.
- **Positive feedback** has a destabilizing effect and does not result in **homeostasis.**
- It is less common than negative

- Interactions are maintained via **feedback mechanisms**, controlling secretion concentrations based on body activity.
- The interaction between the **pituitary** and other **endocrine glands** exemplifies a feedback mechanism, common in living systems.
- **Feedback in thyroid gland function:**
- **Low body temperature** or stress stimulates **neurosecretory cells** of the **hypothalamus**, releasing hormones that trigger the release of
- **Thyroid-stimulating hormone (TSH)** from the **anterior pituitary.**
- **TSH** stimulates the **thyroid gland** to release **thyroxine ($T_4$).**
- **Thyroxine** increases the metabolic activity of most body cells, generating **ATP** and heat.
- Raised body temperature and higher **thyroxine** levels inhibit the releasing-hormone cells and the **TSH-producing cells**, completing the feedback loop.

feedback but plays crucial roles in certain processes.

**BTB**

- Different hormones act as a system of check and balance to maintain homeostasis
- Another example of positive feedback is the suckling action by a baby, which stimulates further milk production.

mentr

# REPRODUCTION

## REPRODUCTION

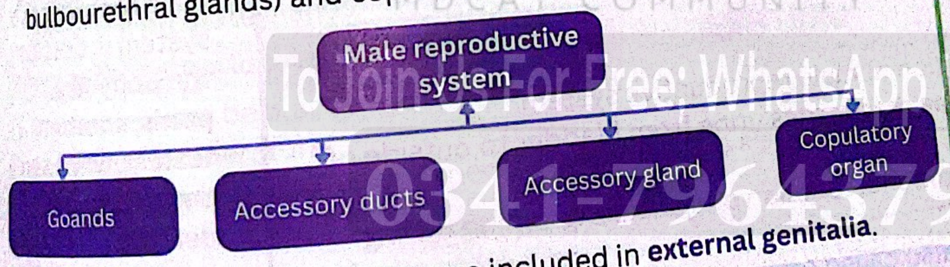
- The ability of an organism to produce new offspring of its own type is called reproduction.
- It is a unique characteristic of life as it is not essential for the survival of the individual unlike other characteristics of life; it is however, required for the survival of the species.
- Without reproduction, the species will cease to exist if all of the members of present generation have died.
- It guarantees the transmission of genetic material of one generation to the other generation.
- Reproduction is a fundamental process and seen in all organisms.

## HUMAN REPRODUCTIVE SYSTEM

- Human reproduction needs internal fertilization. The reproductive system is unique in two respects.
- **Firstly**, the fact that it does not become functional until it is 'turned on' at puberty by the action of sex hormones. In contrast, all other body systems are functional at birth or shortly thereafter.
- **Secondly**, the other organ systems of the body exhibit slight differences in male and female while the reproductive system is quite different in male and female.

## MALE REPRODUCTIVE SYSTEM

- The main function of the male reproductive system is to produce and maintain sperms.
- The male reproductive system includes gonads (testes), accessory ducts, accessory gland (seminal vesicles, prostate gland, bulbourethral glands) and copulatory organ (penis).




- Gonads and copulatory organs are included in **external genitalia**.

### GONADS

- The testes (paired structure) are male gonads which are situated outside the abdomen within a skin pouch called scrotum.
- Each testis is divided into **250 to 300 lobules**.
- Each lobule contains one to four tightly coiled seminiferous tubules.
- The inner epithelia (germinal epithelium) of these tubules in the presence of ICSH produce sperm (spermatogenesis).

### ACCESORY DUCTS

**KPK**

- Humans are the most advanced mammals with an efficient reproductive pattern, especially in protecting the **embryo** within the female body and caring for it after birth.

**KPK**

- About **10 to 20 vasa efferentia** collect sperms from the testes and transfer them to the **epididymis**.
- The **epididymis** rests behind each testis.
- Urethra opens to the outside at the external urethral orifice and conveys both urine and semen.
- **The Seminal Vesicles** provide an alkaline fluid containing **fructose**, **ascorbic acid**, **vesiculase**, and other substances that enhance **sperm motility** thus improving their fertilizing power.
- The **Prostate** secretion is a milky, slightly acidic fluid that contains citrate as a nutrient source and several

**Accessory ducts**

- Vas effrentia
- Epididymis
- Ductus deferens
- Ejaculatory duct
- Urethra

➤ Once spermatozoa are produced, they move through the seminiferous tubules and enter a **tubular network** called the **rete testis** for further maturation.

➤ The spermatozoa are transported out of the testis by a series of **efferent ductules.**

## EPIDIDYMIS

➤ The **epididymis** is coiled on the outer surface of the testis.

➤ Its uncoiled length is **6m or 20 feet (largest duct).**

➤ The epididymis functions in the transport, storage and maturation of the sperms.

➤ Here the sperms are stored temporarily, nourished, and they gain the ability to swim.

## VAS DEFERENS

➤ Epididymis opens into another duct called **ductus deferens (sperm duct or vas deferens)** which joins with the duct of the seminal vesicle to form the short ejaculatory duct.

➤ Vas deferens is a long muscular tube that travels from epididymis into the pelvic cavity to just behind the bladder.

## EJACULATORY DUCTS

➤ The two-vas deferens and two seminal vesicles join to form ejaculatory duct.

➤ Each ejaculatory duct enters the prostate gland, where it empties into the urethra.

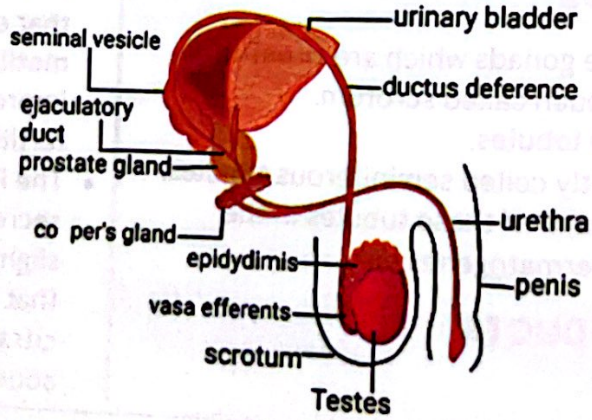
## URETHRA

➤ It is the terminal portion of male reproductive system.

➤ The urethra is the tube that carries urine from bladder to outside of the body.

➤ In male, it has the additional function of ejaculating semen during sexual excitement.

➤ Therefore, urethra is also called urinogenital duct.




enzymes, especially hyaluronidase.

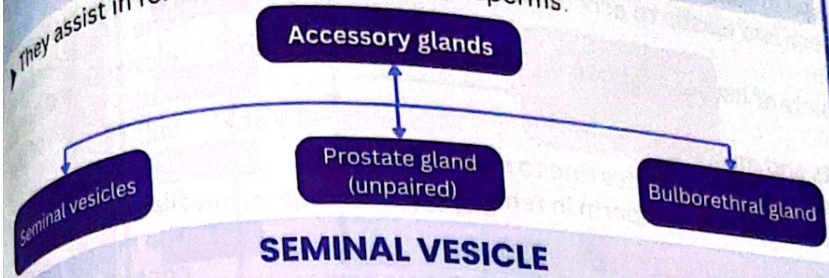
- **Cowper's gland** secretes mucus and an alkaline fluid into the urethra.
- The alkaline fluid neutralizes the acidity of urine in the urethra.
- The Bulbourethral Glands produce thick and clear mucus.

**BTB**

- The male reproductive system performs following **main functions:**
- To **produce and secrete male sex hormones,** maintaining the male reproductive system.
- Unlike the female system, most of the male reproductive system is outside the body (e.g., **penis, scrotum,** testes), while some parts (e.g., **vas deferens, seminal vesicles, prostate gland, Cowper's gland**) are inside.
- The **testes** are oval-shaped organs about the size of large olive seeds.
- The scrotum is a pouch-like sac of skin hanging behind and below the **penis.**
- The **scrotum** acts

## ACCESORY GLANDS

- They assist in formation & movement of sperms.

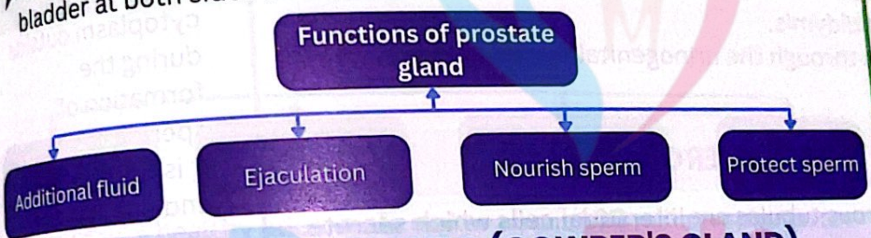



## SEMINAL VESICLE

- **A pair of seminal** vesicles is located at the junction of sperm duct and ejaculatory duct.
- These are sac like pouches that are attached to vas deferens near the base of the bladder.
- It produces a sugar rich fluid that provides sperms with a source of energy to help them move.

## PROSTATE GLANDS

- These are walnut size structures that are located below the urinary bladder at both sides of urethra.




## BULBOURETHRAL GLANDS (COWPER'S GLAND)

- **A pair of bulbourethral glands** is situated at the junction of ejaculatory duct and urethra.
- These are **pea sized structures** located on the side of urethra, just below the prostate glands.

**Why are the testes located outside the abdominal cavity?**

- The testes work best at temperatures slightly less ( almost 2 °C) than core body temperature.
- The optimum temperature for sperm development is about 35°C.

## SEMEN

- Semen is a **white, sticky mixture of sperm** and secretions of accessory glands.
- The liquid substance in the semen provides nutrients and protection to sperms and acts as a transport medium for sperms.
- **Prostaglandins** in semen decrease the viscosity of mucus guarding the entry (cervix) of the uterus and stimulate reverse peristalsis in the uterus, facilitating sperm movement through the female reproductive.
- The amount of semen propelled out of the male duct system during ejaculation is about **2-5 ml** and there are between **20 to 150 million sperm per ml**.

## COPULATORY ORGAN (PENIS)

as a **climate control system** for the **testes**, maintaining a slightly cooler temperature than the body for normal **sperm development**.

- The testes contain coiled **seminiferous tubules**.
- About **100 million sperms** are released into the vagina during intercourse, with only one fertilizing the egg.

**KPK**

- The sperm, or spermatozoon (animal seed), is a very small haploid cell.
- It has a head, a neck, a midpiece, and a tail.
- The **head** has a diameter of **2.5um**.
- The **head** contains a large nucleus with a little cytoplasm having **haploid set of chromosomes**.
- Adhering to the top of the head is **acrosome**.
- The lysosome-like acrosome is produced by the Golgi apparatus and contains hydrolytic enzyme **hyaluronidase** that enables the sperm to penetrate and enter an egg.
- The **neck of sperm** is very short and contains a pair of

- It is the male organ used in sexual intercourse.
- The skin of penis is loose and elastic to accommodate changes in penis size during an erection.
- The penis consists mainly of tissues that can fill with blood to cause an erection.
- It is composed of ducts and muscles.
- When Blood pressure increases in muscles due to sexual arousal it becomes erect and is used to transfer sperm in female body.

**PTB**

**Functions of sertoli cells**

- Liquid medium
- Protection
- Nourishment to sperms

- The sperms are transferred from seminiferous tubules to the main duct of the male reproductive tract, the vas deferens, which forms highly convoluted epididymis.
- The sperms then pass through the urinogenital duct and 'are discharged out.

## TESTOSTERONE

- Between the seminiferous tubules are interstitial cells which secrete testosterone.
- This hormone is essential for the successful production of sperms and controls the development of male secondary sexual characteristics during puberty.

| Features | Hormones | | | | |
|---|---|---|---|---|---|
| | GnRH | FSH | LH/ICSH | Testosterone | Inhibit |
| Released From | Hypothalamus | Anterior pituitary | Anterior pituitary | Leydig cells | Sertoli cells |
| Chemical Nature | Polypeptide | Glycoprotein | Glycoprotein | Steroid | Protein |
| Role | Control the release of pituitary gonadotropins | Stimulate spermatogenesis. Stimulate sertoli cells | Stimulates Leydig cells to release testosterone | Growth and development of germinal epithelium | Control the spermatogenesis at normal rate. |

## SPERMATOGENESIS

- Each testis consists of a highly complex duct system called **seminiferous tubules**, in which repeated division by the cells of the germinal epithelium produce **spermatogonia**.
- Spermatogonia divide by mitosis forming a **primary spermatocyte**.
- **Primary spermatocytes** undergo meiotic division to form **secondary spermatocytes (Meiosis I)** and **spermatids (Meiosis II)**.
- Eventually, the spermatids differentiate into mature sperms.

centrioles.

- The microtubules of one of the centrioles elongate and run the entire length of the tail.
- It forms the axial filament of the tail.
- The **middle piece** contains many mitochondria arranged spirally around the axial filament.
- Mitochondria provide energy during motility in female tract.
- The **tail** forms due to shedding of cytoplasm outside during the formation of spermatids.
- It is flagellum like and enables the sperm to move towards egg.
- The process of sperm formation begins around the age of **14 years** in males and continues throughout life.

**KPK**

- Spermatogenesis takes place in **seminiferous tubules**. Spermatogonia are the **outermost** cells which make the epithelial wall of the seminiferous tubules
- These cells are just beneath the basal **lamina**.

**spermatogenesisi**

Germinal epithelium **(2n)**
↓ mitosis
Spermatogonia **(2n)** → Type A cells remain at basal lamina as seem cells
↓ mitosis
Type B daughter cells
↓ mitosis
Primary spermatocyte **(2n)**
↓ mitosis
Secondary spermatocyte **(n)**
↓ mitosis

**spermiogenesisi**

Early spermatids **(n)**
↓
Late spermatids **(n)**
↓
Sperms **(n)**

- **The spermatogonia divide continuously by mitosis and, each mitotic division of a spermatogonium results in two distinctive daughter cells-types A and B.**
- **The type A daughter cell remains at the basement membrane to maintain the germ cell line.**
- **The type B cell gets pushed toward the lumen, where it becomes a primary spermatocyte destined to produce four sperm.**

**FTB**

**Spermatid**
- Round
- Non-mobile
- Haploid cell
- Immature cell

Every day, a healthy adult male makes about **400 million sperms**. (24-48 hours life Span)

**BTB**

- FSH and LH are produced by the pituitary gland located at the base of the brain.
- FSH is necessary for sperm production and LH is necessary to continue the process of spermatogenesis.

## SPERMIOGENESIS

- **Spermiogenesis** is a process in which spermatids change into motile and active sperms.
- During this process a spermatid elongates, sheds its excess cytoplasm, and forms a tail.



## HORMONAL CONTROL

- Process of spermatogenesis is controlled by hormonal secretions from hypothalamus and pituitary gland.
- The hypothalamus releases gonadotropin- releasing hormone (GnRH), which controls the release of the anterior pituitary gonadotropins follicle-stimulating hormone (FSH) and luteinizing hormone (LH).

**BTB**

- Ovaries are oval-shaped and attached to the dorsal body wall just below the kidneys.
- Eggs or ova develop inside the ovaries of mature female.
- There are approximately

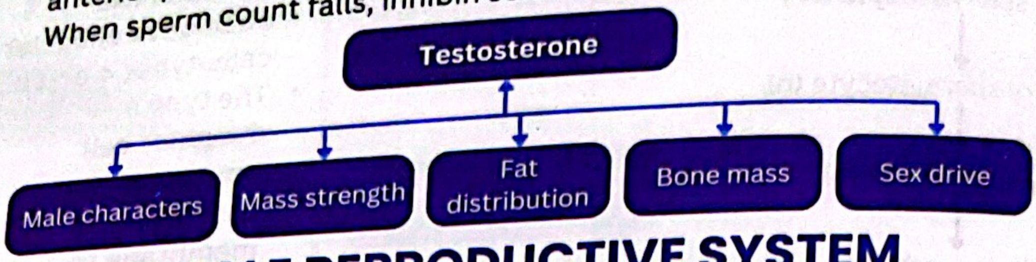
## FOLLICLE STIMULATING HORMONE

- FSH stimulates spermatogenesis by stimulating the Sertoli cells to complete the development of sperms from spermatids.
- Sertoli cells are elongated cells found in the seminiferous tubules of the testis, and they nourish the spermatids.

## LUETINIZING HORMONE

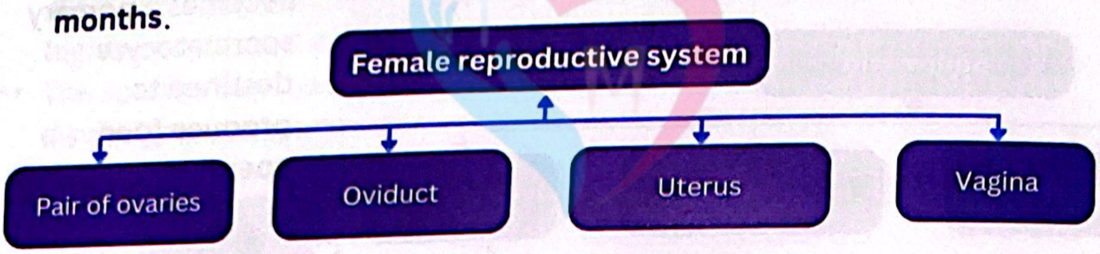
- LH stimulates Leydig cells (found adjacent to or between the seminiferous tubules in the testicle) to release testosterone.

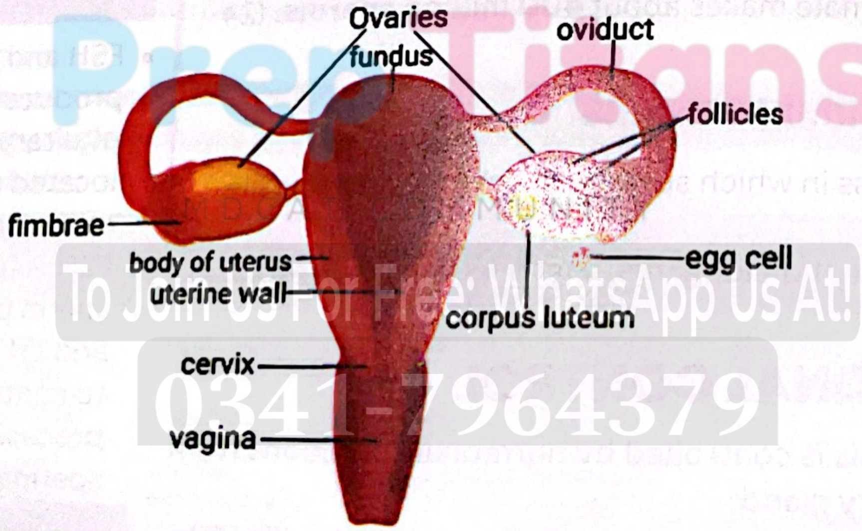
- Leydig cells are also called interstitial cells.
- Testosterone causes the growth and development of germinal epithelium to form sperms.
- Inhibin hormone is produced by the Sertoli cells and serves to control the spermatogenesis at normal rate.
- When the sperm count is high, inhibin release increases and it inhibits anterior pituitary release of FSH and hypothalamic release of GnRH. When sperm count falls, inhibin secretion declines steeply.




## FEMALE REPRODUCTIVE SYSTEM

- The reproductive role of the female is far more complex than that of a male.
- Not only must she produce gametes, but her body must prepare to nurture a developing embryo for a period of approximately **nine months**.






### OVARIES

- Ovaries are female gonads which produce ova and release hormones.
- The paired ovaries flank the uterus on each side and each ovary is held in place within the peritoneal (body) cavity by several ligaments.
- The ovaries are almond-shaped, solid, ovoid structure measure about **3-5 cm** long and **2-3 cm wide**.
- Within the ovary are many tiny saclike structures called **ovarian follicles** each of which consists of an immature egg, called an **oocyte**.
- Each month in adult women, one of the ripening follicles ejects its oocyte from the ovary. This event is called ovulation.
- After ovulation, the ruptured follicle is transformed into a glandular

4,000,00 potential (follicles) cells are already present at birth, only about **500** will ever become mature within two they ovaries and they are released from puberty to menopause.

- Usually, only one egg is released every month.
- The ovaries take turns alternate to release an egg.
- The egg is spherical in shape and about **120μm** in diameter, containing a large nucleus with haploid number of chromosomes.
- The female reproductive system is also under the influence of menstrual cycle.

**KPK**

- The uterus is located in the pelvis, anterior to the rectum and posterior to the bladder.
- The uterine tube contains sheets of smooth muscle and contains both ciliated and non-ciliated cells.
- Non-ciliated cells produce a secretion that keeps the oocyte (and sperm, if present) moist and nourished.

structure called the **corpus luteum.**

## OVIDUCT (UTERINE TUBE)

- Fallopian tubes or oviducts form the initial part of the female duct system. They are narrow muscular tubes.
- They receive the ovulated oocyte and are the site where fertilization generally occurs.
- The fertilization of the ovum takes place in the **proximal part of the oviduct.**
- Each oviduct is about **10 cm long** and extends near the region of an ovary to empty into the uterus.
- The oocyte is carried toward the uterus by a combination of **muscular peristalsis** and the **beating of the Cilia.**

## UTERUS

- The uterus or womb is a hollow, thick-walled muscular organ, sized and shaped somewhat like an **inverted pear.**
- The uterus has **three portions:** the fundus, the body and the cervix.
- Fundus is the upper muscular portion.
- Body is the hollow muscular area where the embryo is implanted.

## CERVIX

- It is a narrow entrance from uterus to vagina.
- It is normally blocked by a plug of mucous.
- At the lower narrow end of the uterus is a circular ring of muscle known as cervix.
- Urethra and vagina have independent openings to the exterior.

## LAYERS OF UTERUS

- The oviducts join the uterus just below the fundus and the opening of the cervix leads to the vaginal canal.
- The wall of the uterus is composed of **three layers.**
- The **perimetrium** is the **outermost** thin covering layer of uterus.
- It serves the purpose of protection.
- The **myometrium** is the **middle thick muscular layer** composed of bundles of smooth muscle, which contracts rhythmically during childbirth to expel the baby from the mother's body.
- The **endometrium** is the **inner spongy lining** of the uterine cavity.
- If fertilization occurs, the young embryo is implanted into the endometrium and resides there for the rest of its development.
- The **main functions** of uterus are to receive, retain, and nourish a fertilized ovum.

**PTB**

- The fertilized ovum (zygote) enters the uterus where it is implanted (conceived) and undergoes further development.
- A placenta is established between the uterine and foetal tissues for the exchange of oxygen, carbon dioxide, waste, nutrients and other materials.

**BTB**

- Fallopian tubes are about **12cm** long and wide as a sewing needle.
- The Uterus is an elastic sac of about **7.5 cm** long.
- It is the site for the development of the fetus.
- The opening of the vagina is called vulva.
- Semen is deposited in the vagina during intercourse.

**TERMS USED FOR OVUM**

- **Zona pellucida** is a thick transparent membrane surrounding a mammalian ovum before implantation.
- **Corona radiata** is many layers' thick follicle cells adhering to oocyte which supply vital proteins to the cell.
- **Corpus albicans** is regressed form of the corpus luteum.

**KPK**

- The reproductive cycle in human and other primates is called menstrual cycle.
- The uterine or menstrual cycle is a series of cyclic changes that the uterine endometrium goes

## VAGINA (EXTERNAL GENITALIA)

- The vagina is a thin walled **8-10 cm long tube** and extends from the cervix to the body exterior.
- It is often called the **birth canal** as it provides a passageway for delivery of an infant and for menstrual flow.
- The urethra is embedded in its anterior wall.

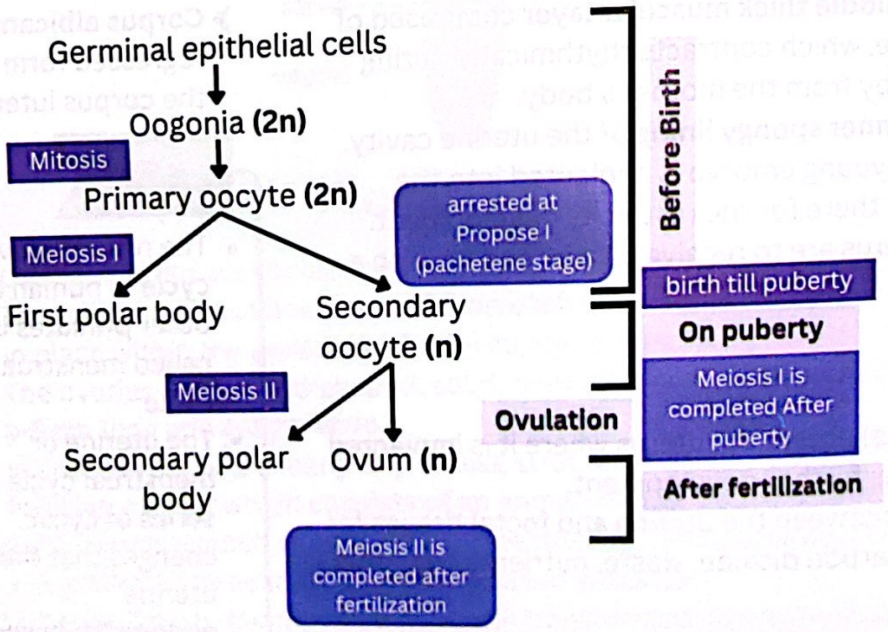
| Features | Spermatogenesis | Oogenesis |
|---|---|---|
| Location | Occur in tests | Occur mainly in ovaries |
| Meiotic Division Results in | Equal division of cytoplasm | Unequal division of cytoplasm |
| Number of Gametes Produce | Four | One and two to three polar bodies |
| Size of Gamete | Relatively smaller | Relatively larger |
| Duration | Un-interrupted process | Interrupted process |
| Onset | Begins at puberty | Begins during fetal life |
| Release of gametes | Continuous | Month (From puberty all menopause) |
| End | Lifelong (But reduces with age) | Terminates with menopause |
| Growth phase | Short | Prolonged |
| Gamete Motility | Yes | No |

## DO YOU KNOW?

- The reproductive system contains 1 the **largest cell** of the body: the **egg**, which is about **120mu in diameter** and **smallest human cell:** the **sperm**, about **5mu in diameter**.
- A female uterus is normally about 3 inches long and 2 inches wide which can expend up to 20 times during pregnancy. Uterus contains one of the strongest muscles in the female body.
- It has been assumed that a female's total supply of eggs is already determined by the time she is born, and the time span during which she releases them extends only from puberty to menopause, about the age of 50.



## OOGENESIS




through each month as it responds to the waxing and waning of ovarian hormones in the blood.

- These endometrial changes are coordinated with the phases of the ovarian cycle.
- Under the influence of rising blood levels of estrogens, the basal layer of the endometrium generates a new functional layer during proliferative phase.

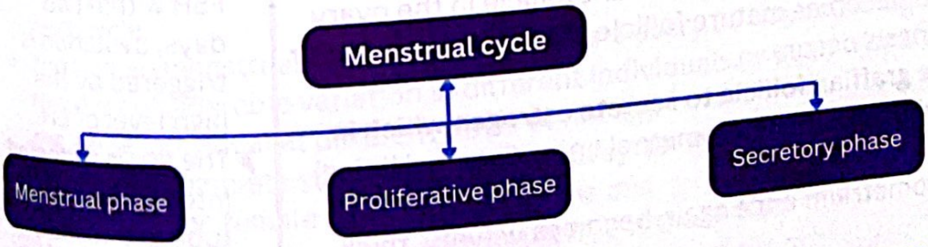
### BTB

- **Estrogen**, which helps in the maturation of egg while LH stimulates the production of progesterone in ovaries.
- The estrogen triggers the development of secondary sexual characteristics in female.
- The pituitary gland also produces **prolactin**, which stimulates milk production.
- **Oxytocin**, which stimulates uterine contraction during childbirth and milk let down during sucking.
- The start of monthly discharge of blood or menses

- The process of **egg formation** in females is called oogenesis.
- It is initiated at the stage of fetus and takes years to complete
- First, in the fetal period the **oogonia**, the diploid stem cells of the ovaries, multiply rapidly by mitosis and then enter a growth phase and lay in nutrient reserves.
- Gradually the oogonia are transformed into **primary oocytes** and become surrounded by a single layer of follicle cells.
- The primary oocytes begin the **first meiotic division** but become "stalled" late in prophase I and do not complete it.
- They remain in this state for about **10-14 years** until puberty.
- At puberty, a small number of primary oocytes are recruited each month, however, only one is selected each time to continue meiosis I, ultimately producing two haploid cells (that are quite dissimilar in size.
- The larger cell, which contains nearly all the cytoplasm of the primary oocyte, is the **secondary oocyte** and the smaller cell is called the **first polar body**.
- In humans, the **secondary oocyte arrests in metaphase II** and it is this cell that is ovulated.
- If an ovulated secondary oocyte is not penetrated (fertilized) by sperm, it simply deteriorates.
- But, if sperm penetration does occur, it quickly completes **meiosis II**, yielding **one large ovum** and a **tiny second polar body**.
- In human only one ovum is usually discharged from the ovary at one time, this phenomenon is called **ovulation**.
- The unequal cytoplasmic divisions that occur during oogenesis ensure that a fertilized egg has ample nutrients for its **six- to seven-day journey to the uterus**.
- Without nutrient-containing cytoplasm the polar bodies degenerate and die.

# FEMALE REPRODUCTIVE CYCLE

- In females, egg production is cyclic, unlike males where gamete production and release are continuous from puberty throughout life.
- The **menstrual cycle** in human females averages **28 days** and involves structural and functional changes in the **ovaries** (ovarian cycle) and **uterus** (uterine cycle), regulated by **pituitary gonadotropins**. Variations from **21-33 days** are normal.
- The cycle is divided into three phases based on hormonal changes.




**NOTE**

In PTB and BTB Ovulation is also included in the stages of menstrual cycle so total stages according to them will be four.

from uterus via vagina is the first sign of puberty in female.

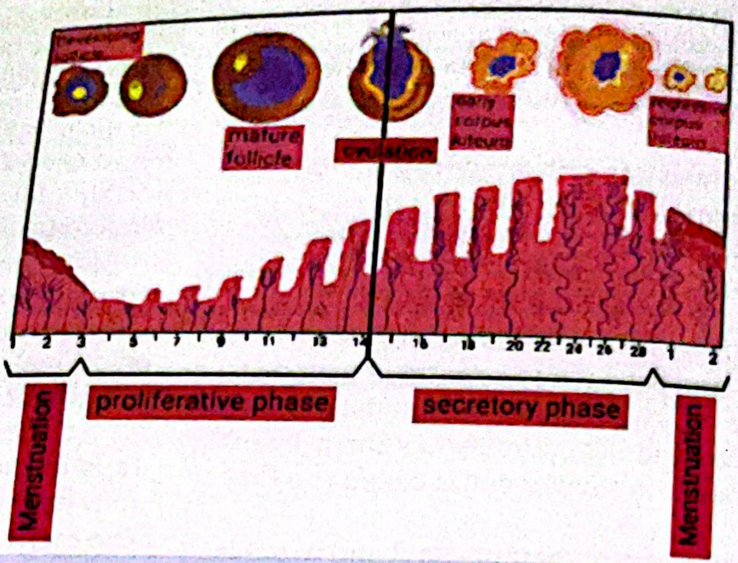
- The length of the menstrual period and amount of blood lost vary considerably with the individual.
- The effects of emotional disturbances, stress, mental fatigue and illness may alter or stop the menstrual cycle.
- An unbalanced diet or malnutrition may cause the periods to be very irregular or to stop completely.
- A young girl may take about three years before her periods become regular.

### MENSTRUAL PHASE

- Menstrual fluid contains blood, cells from the lining of the uterus and mucus.

### FOLLICULAR PHASE

- The follicular phase starts at the stoppage of menstruation and ends with ovulation.
- The pituitary gland releases follicle stimulating hormone (FSH), which stimulates the ovary to produce about **5-20 follicles**.
- Each follicle houses




## MENSTRUAL PHASE (AVERAGE LENGTH 1-5 DAYS)

- In this menstruation phase, the uterus sheds all but the deepest part of its endometrium, the thick, hormone-dependent functional layer of the endometrium detaches from the uterine wall, a process that is accompanied by bleeding for **3-5 days**.
- The detached tissue and blood pass out through the vagina as the menstrual flow.
- At the **beginning** of this stage, **ovarian hormones** are at their **lowest normal** levels and **gonadotropins** are beginning to **rise**.
- Then FSH levels begin to rise.

**PTB**

- Menstruation stage usually lasts for 3 - 7 days.



## PROLIFERATIVE/PRE-OVULATORY PHASE (6-14 DAYS)

- Through the influence of a rise in follicle stimulating hormone (FSH) during the first days of the cycle, a few ovarian follicles (primary) are stimulated.
- These follicles compete with each other for dominance.
- As a result, all but one of these follicles stop to grow and finally disintegrate **(follicle atresia)**, while one dominant follicle in the ovary continue to mature and becomes mature follicle **(Graafian or vesicular follicle)**, in which oogenesis occurs.
- FSH also stimulates the graffian follicle to secrete estrogen which in turn governs the vascularization of endometrial lining (internal lining) of uterine wall.
- Consequently, the endometrium once again becomes velvety, thick and well vascularized.
- Normally, cervical muscles is thick and sticky but rising estrogen levels cause it to thin and become crystalline, forming channels that facilitate the passage of sperm into the uterus.
- Estrogen has **negative feedback** upon **FSH**, therefore, as the concentration of estrogen rises the level of FSH falls.

an immature egg.

- The growth of the follicles stimulates the lining of the uterus to thicken in preparation for possible pregnancy.

**OVULATION STAGE**

- Ovulation is the release of a mature egg from the surface of the ovary. This usually occurs mid of the cycle, about the **14th day** of the cycle.
- During the follicular phase, the development of follicles causes a rise in the level of estrogen.
- The hypothalamus in the brain recognizes these rising levels and releases a chemical called gonadotropin releasing hormone (GnRH).
- This hormone stimulates the pituitary gland to produce raised levels of luteinizing hormone (LH) and FSH within two days, ovulation is triggered by the high level of LH.
- The egg is funneled into the fallopian tube and toward the uterus by waves of small hairlike projections.
- The life span of the typical egg is only around **24 hours**.

- This is a signal for anterior pituitary to release LH, at the end of the proliferative stage (day 14) in response to the sudden release of LH from the anterior pituitary causes the release of developing egg from the mature follicle into the oviduct, the event is known as **ovulation**, which takes less than five minutes.
- LH also converts the ruptured follicle to a yellowish glandular mass called corpus luteum.

## SECRETORY/POST OVULATORY PHASE (DAYS15-28)

- During the secretory phase, the endometrium prepares for implantation of an embryo.
- It is a **14-day phase** and its time duration is fixed.
- Rising levels of progesterone from the corpus luteum act on the estrogen-primed endometrium causing the arteries to elaborate and converting the functional layer to a glandular secretory layer (uterine glands).
- Progesterone develops the endometrium and make it receptive for the implantation of the zygote (placenta formation).
- The uterine glands enlarge, coil and begin secreting nutritious glycogen into the uterine cavity.
- These nutrients sustain the embryo until it has implanted in the blood-rich endometrial lining.
- If fertilization has not occurred, the corpus luteum begins to degenerate toward the end of the secretory phase as LH blood level declines.
- Progesterone levels fall, depriving the endometrium of hormonal support and endometrial cells die, setting the stage for menstruation to begin on day **28**.
- This causes the discharge of blood and cell debris known as menstruation.
- In human beings, menstrual cycle ceases around **50 years** of age, and it is termed as menopause.
- Cyclic menstruation is an indicator of normal reproductive life of females and extends between menarche (first menstruation at puberty) and menopause.



**PTB**

- The cycle is thus completed, and the uterus is ready to enter into the next cycle.
- The human menstrual cycle generally repeats every **28 days** although there is considerable variation in different individuals or even within the same individual at different times of her age.
- The end or complete stop of the menstrual cycle is called menopause, after which the female stops producing the ova.
- Malnourishment and emotional stresses effect the female reproductive cycle, which may be disturbed. The cycle is not completed in its normal **28 days**.
- The release of a secondary oocyte (ovulation) is timed to coincide with the thickening of the lining of the uterus.
- The uterine cycle in humans involves the preparation of the uterine

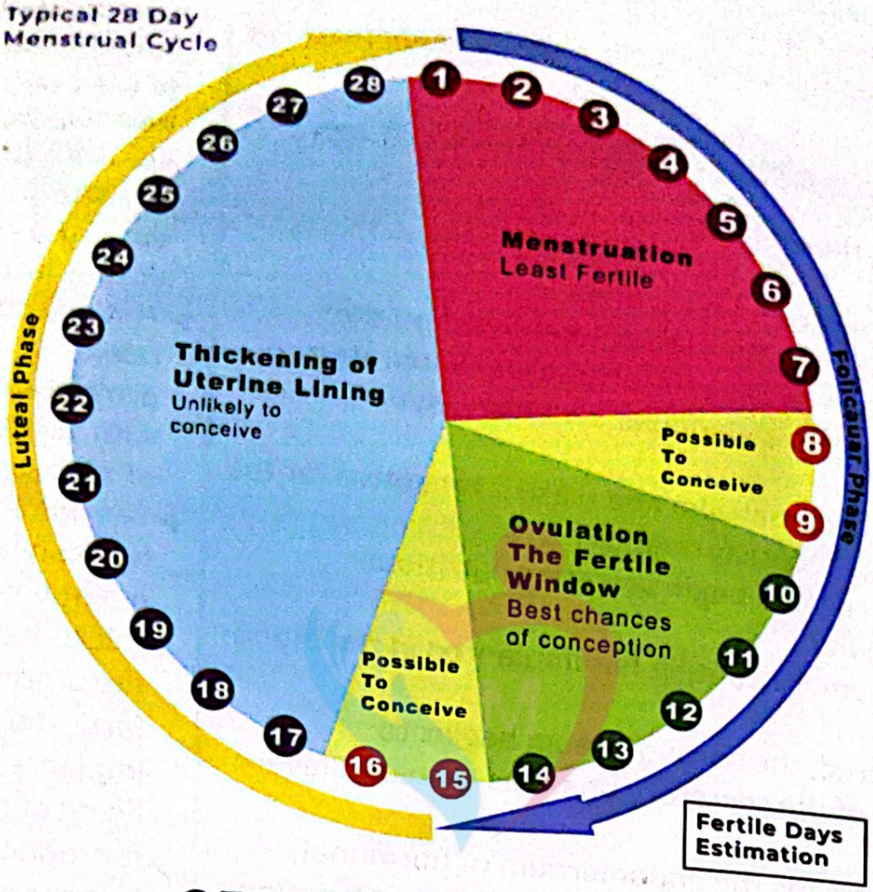
**LUTEAL PHASE**

- During ovulation, the egg bursts out from its follicle, but the ruptured follicle stays on the surface of the ovary for the next two weeks or so. The follicle transforms into the structure called corpus luteum.
- This structure starts releasing progesterone along with small amounts of estrogen.
- The combination of hormones maintains the thickened lining of the uterus of fertilized egg implants in the lining of the uterus.
- It produces the hormones that are necessary to maintain the corpus luteum.
- It induces human chorionic gonadotropin (hCG), the hormone that is detected in urine test for pregnancy. If pregnancy does not occur, the corpus luteum degenerates usually during day **22** after menstruation.

**KPK**

- Bacterium invades the mucosae of the reproductive and urinary tracts.
- The most common

wall to receive the embryo if fertilization occurs.
- Knowing how these two cycles compare, it is possible to determine when pregnancy is most likely to occur




# OESTROUS CYCLE

- Oestrous cycle is a reproductive cycle found in all female mammals except human being.
- In this cycle, the oestrogen production prepares the uterus for conception partly and also follicle develops ova.
- At this stage, female needs a physical stimulus of mating for ovulation. She exhibits the desire for mating or is said to be on "heat"



## FOR YOUR INFORMATION

- In **1-2%** of all ovulations, more than one oocyte is ovulated.
- This phenomenon, which increases with age, can result in multiple births.
- Since, in such cases, different oocytes are fertilized by different sperm, the siblings are fraternal, or nonidentical, twins.
- Identical twins result from the fertilization of a single oocyte by a single sperm, followed by separation of the fertilized egg's daughter cells in early development
- Fertile duration in the **28 days** menstrual cycle lasts from **9-15 days**.

# SEXUALLY TRANSMITTED DISEASES

- These are contagious diseases that are caused by pathogens that are passed from one human to another by sexual contact.
- STDs are caused by bacteria and viruses.
- Gonorrhoea and syphilis are caused by bacteria.

symptom of gonorrhea in males is urethritis, accompanied by painful urination and discharge of pus from the penis.
- Symptoms vary in women, ranging from none (about 20% of cases) to abdominal discomfort, vaginal discharge, abnormal uterine bleeding, and occasionally, urethral symptoms similar to those seen in males.
- Untreated gonorrhea can cause urethral constriction and inflammation of the entire male duct system.
- In women, it causes pelvic inflammatory disease and sterility. It can be treated by penicillin, tetracycline, and certain other antibiotics.

**BTB**

- There is no blood test to diagnose gonorrhoea. In male, typical symptoms are pain upon urination and a thick greenish yellow urethral discharge.
- Gonorrhoea can spread to internal parts of the body.

## EXAMPLES

Some examples of sexually transmitted diseases are chlamydia, gonorrhoea, syphilis, genital herpes, AIDS, etc.

## GONORRHEA

- It is caused by a **gram-positive bacterium** Neisseria gonorrhoeae, mainly affecting the mucous membrane of urinogenital tract.
- Newborn infants may acquire serious eye infections if they pass through the infected birth canal.
- It is highly contagious through sexual contacts.

## SYPHILIS

- It is caused by a spirochaete, **Treponema pallidum**.
- It damages the reproductive organs, eyes bones joints, central nervous system, heart, and skin.
- Sexual contact is the major source of its dissimination.

**KPK**

- It can be contracted congenitally from an infected mother. Fetuses infected with syphilis are usually stillborn or die shortly after birth.
- The bacterium easily penetrates intact mucosae and abraded skin.
- Within a few hours of exposure, an asymptomatic body wide infection is in progress.
- After an **incubation period** of **two to three** weeks, a red, painless primary lesion called a **chancre** (shang'ker) appears at the site of bacterial invasion.
- In males, this is typically the penis, but in females the lesion often goes undetected within the vagina or on the cervix.
- The chancre ulcerates and becomes crusty; then it heals spontaneously and disappears within a few weeks.
- If syphilis is untreated, its secondary signs appear several weeks later.
- A pink skin rash all over the body is one of the first symptoms.
- Fever and joint pain are common.
- These signs and symptoms disappear spontaneously in three to twelve weeks.
- Then the disease enters the latent period and is detectable only by a blood test.
- The latent stage may last a person's lifetime (or the bacteria may be killed by the immune system), or it may be followed by the signs of tertiary syphilis.
- Tertiary syphilis is characterized by gummas, destructive lesions of the CNS, blood vessels, bones, and skin.
- Penicillin is still the choice of treatment for all stages of syphilis.

## GENITAL HERPES

- It is caused by a herpes simplex **type 2 virus**, most frequently transmitted by sexual contact causing infection of the genitalia.
- In infected pregnant woman, virus can be transmitted to infant during birth, causing damage to eyes and CNS of the infant.

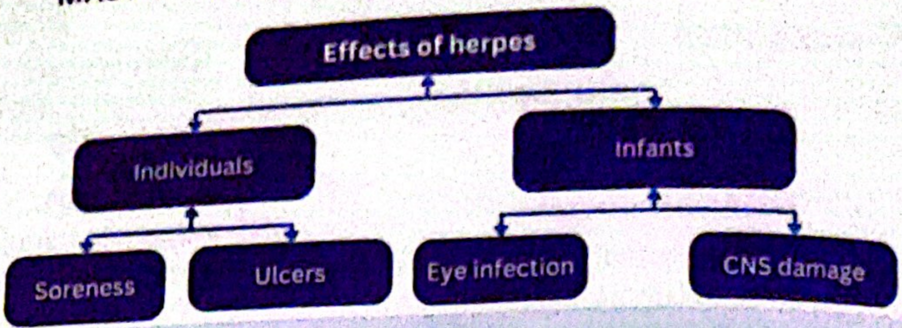
causing heart damage or arthritis.

**BTB**

- Syphilis has three stages, which are typically separated by latent periods.
- In the primary stage, a hard chancre (ulcerated sore with hard edges) appears.
- In the secondary stage, rash appears all over the body.
- During the tertiary stage, syphilis may affect the cardiovascular and nervous system.
- Syphilis is a very devastating disease.
- Control depends on prompt and adequate treatment of all cases being treated with antibiotic therapy.

**BTB**

- HIV can be diagnosed through rapid diagnostic tests. However, there is still no cure for AIDS.
- If you require acupuncture, ear, piercing, nose piercing, etc. You should go to reliable operators and make sure that needles used are sterilized or insist on using disposab[le] instruments.




- Blood of donor must be screened before transfusion.
- Use disposable syringes and sterilized operation tools for surgery.

## AIDS

- AIDS is caused by the human immunodeficiency virus (HIV).
- HIV destroys a type of defense cell in the body called a **CD4 helper lymphocyte**.
- These lymphocytes are part of the body's immune system, the defence system that fights infectious diseases.
- But as HIV destroys these lymphocytes, people with the virus begin to get serious infections that they normally wouldn't- that is, they become immune deficient.
- Medical community have been able to develop drugs to inhibit it (meaning they interfere with its growth).
- These drugs have been successful in slowing the progress of the disease, and people with the disease now live much longer. But there is still no cure for HIV and AIDS.
- HIV can be **transmitted** from an infected person to another person through blood, semen vaginal fluids, and breast milk.
- The virus is spread through high-risk behaviors including immoral sexual behaviour, sharing needles, such as needles used to inject drugs, needles used for injecting steroids and those used for tattooing.
- People who have another sexually transmitted disease, such as syphilis, genital herpes, gonorrhea, or bacterial vaginosis are at greater risk for getting HIV.
- If a woman with HIV is pregnant, her newborn baby can catch the virus from her before birth, during the birth process, or from breast feeding.



| Feature | Gonorrhea | Syphilis | Genital Herpes | AIDS |
|---|---|---|---|---|
| Causative Agent | Gram positive bacteria | Spirochaete | Virus | Virus |
| Name of pathogen | *Neisseria gonorhoeae* | *Treponema pallidum* | *Herpes simplex type II* | *HIV* |
| Main parts Affected | Mucous membrane of urinogenital tract, eye infection to baby. | Damage to reproductive organs, eyes, bones, joints, CNS, heart, skin. Infection proceeds in 3 stages. | Infection of genitalia, genital soreness & ulcers, damage to eyes & CNS in infants. | Destruction of immune system |
| Source of Transmission | Sexual contact | Sexual contact | Sexual Contact | Sexual Contact |
| Treatment | Antibiotics | Antibiotics | Anti-viral drugs | Anti-viral drugs |

# GENETICS

## Genetics

- The similar characteristics that pass from parents to their offspring are collectively called **heredity.**
- The resemblance, however, is not complete, offspring differ from each other and their parents in many respects. These differences are known as **variations.**
- Both similarity and differences are the parts of inheritance which play a significant role in the formation of **new species.**
- The science, which deals with mechanism of the heredity and variation, is called **genetics.**
- Since genes **control the heredity** and variations, so the term genetics is also referred the study of genes

**PTB**

- Gene is the basic unit of biological information.
- In fact, DNA stores all sorts of biological information coded in the sequence of its bases in a linear order, and genes are actually parts of DNA comprising its base sequences.
- The position of a **gene on the chromosome** is called its **locus.**
- Genes are responsible for producing startling inherited resemblances as well as distinctive variations among generations.
- When these pass in the form of intact parental combination between generations, inherited similarities are conserved; but when these shuffle, mutate or juggle with each other, variations emerge.
- **Genes form pairs on pairs of homologous chromosomes.**
- One member of a gene pair is located on one homologue, and the other member on the other homologue.
- Partners of a gene pair are called **alleles.**
- Each allele of a gene pair occupies the same gene locus on its respective homologue.
- Both alleles on one locus may be identical, or different from each
- other.
- **Phenotype** is the form of **appearance of a trait.**
- Genotype is the genetic complement i.e., the genes in an individual for a particular trait.
- A flower may be red or white in color.
- **Flower color is a trait** and red and white are its two phenotypes. Each form of expression is determined by a different allele of the color gene.
- Allele **"R"** is the determiner for redness, while **"r"** is the determiner for whiteness.

**BTB**

- We actually have two genomes.
- We get one copy of our genome from each of our parents.
- Inheritance describes how genetic material is passed on from parent to offspring.
- The simplest form of inheritance was uncovered from the work of **Gregor Mendel in 1865.**
- Variations may be harmful or useful or useless
- Mendelian inheritance refers to the patterns of inheritance that are characteristics of organisms which reproduce sexually.
- On genetic level all humans are more than **99% identical.**
- The term dominant and recessive do not mean that an organism possessing a dominant trait is healthier or more vigorous than an organism with the recessive trait.
- Both dominant and recessive alleles can be disease carriers.

## GENE POOL

- Any group of interbreeding organisms of the same species that exist together in both time and space is called a **population.**
- All the genes / alleles found in a breeding population at a given time

true or pure breeding like P1 round) while **2/3** of $F_2$ round produced both round and wrinkled in **3:1** (appeared non-pure breeding like $F_1$ round), but $F_2$ wrinkled produced only wrinkled (pure breeding)

## INTERPRETATIONS OF THE RESULTS

- Based upon these observations, Mendel concluded that each contrasting form (phenotype) of a trait, e.g, roundness or wrinkledness of seed was determined by **particulate hereditary factors, which he called "elementens (now called genes)**.
- These factors carrying hereditary information were transmitted from parents to offspring through **gametes**.
- Each pea plant had a **pair of these factors** (now called alleles, the alternative form of gene on the same locus), one derived from the male parent and other from the female parent.
- The pair of these factors (now called **genotype**) controlled the expression of the trait now called **phenotype**.
- He designated the term **"dominant"** to the factor that was expressed in F1 generation while the factor that was failed to express, termed as **"recessive"**.
- These factors were represented by **alphabetical symbols** e.g the dominant factor was represented by capital (upper) case letter (**"R" for round seed shape**) and the recessive factor by small (lower case) letter (**"r" for wrinkled seed shape**)
- The true breeding round seed plant of P1 generation carried "RR alleles while the true breeding wrinkled seed plant of P1 generation carried "rr" alleles.
- When both the alleles of a gene pair are same, the organism is said to be **homozygous** for that gene pair.
- An Individual with homozygous genotype is called **homozygote**
- Mendel inferred that the factor of a pair (alleles) separated from each other during gamete formation so that each gamete got only one factor for each trait.
- Therefore, half of the gametes got one allele, and the other half carried the other allele.
- Fertilization was random.
- When male gamete carrying **factor R** fertilized female gamete **carrying factor r**, the complete set of two factors **Rr** for the trait was restored in the zygote.
- Zygote developed into F1 offspring that was **heterozygous** "Rr" because the two alleles of its gene pair were different from each other
- An individual with heterozygous genotype is called **heterozygote**.
- F1 offspring Rr was a monohybrid for seed shape it was round in phenotype but heterozygous in genotype.
- Its alleles also segregated during gamete formation.
- Mendel actually observed **3:1** phenotypic ratio in F2.
- His phenotypic data of F3 can also be explained on the basis of **1:2:1** genotypic ratio of F2.
- Mendel compared the result of all the seven separately studied characters, and found them strikingly similar; therefore, he became able to formulate law of segregation.



- Chromosome ... Seed shape

**MENDEL'S PREDICTION**

- The science of **cytology** was in its primitive state during Mendel's time.
- Mendel visualized the cause of inheritance as factors or elements which were later **named as genes by Johannsen in 1909**
- According to Mendel, each male and female parent contains a pair of factors, and each parent passed only one factor of a pair to their offspring.
- He also predicted that each factor retained its individuality from generation to generation.
- The factors contributed united randomly to produce the characters of the hybrid.
- Thus, he indirectly predicted the reduction in chromosome number during gametogenesis and the physical hereditary mechanism.

**PTB**

- After establishing **14 pure - breeding** lines of seven characters, he cross-fertilized plants that differed in one character only.
- The offspring of such a cross were called monohybrids.

## TEST CROSS

- Mendel devised a cross called test cross, **which is used to test the genotype of an individual** showing a dominant phenotype.
- It is a mating in which an individual showing a dominant phenotype is crossed with an individual showing its recessive phenotype.
- This cross find out the homozygous or heterozygous nature of the genotype
- A phenotypically round seed could be homozygous (RR) or heterozygous (Rr).

| Case 1 Homozygous Parent | Case 2 Heterozygous Parent |
|---|---|
| If the seed is homozygous round (RR) it will grow into a pea plant that forms all gametes with only **R** allele. Wrinkled seed plant is always homozygous recessive, it will form all gametes with r allele. Fertilization will result in 100% round seed progeny. | If the seed is heterozygous round (Rr), it will grow into a plant that forms half the gametes, with 'R' and half with 'r' allele. Wrinkled seed plants will form only 'r' type of gametes. Fertilization will result into 50% round and 50% wrinkled seed progeny. Even a single wrinkled seed in the progeny is convincing proof for the heterozygous nature of the round parents. |
| Round RR × Wrinkled rr<br>R R r r<br>r<br>R Rr | Round Rr × Wrinkled rr<br>1/2 R 1/2 r r r<br>r<br>1/2 R 1/2 Rr<br>1/2 r 1/2 rr |

**FTB**

- R.C. Punnet devised what is known as the **Punnett square** for summarizing the fusion of gametes in genetic crosses
- Punnet was professor of genetics at Cambridge university.
- He wrote a large number of papers between **1900** and **1958**, most of which helped to confirm and extend Mendel's work.
- Observation, assumption, experimentation and creativity, all of them

**KPK**

- According to the classical method of symbolism, the dominant allele is represented by the capital letter while recessive allele by the small letter.
- In the modified method, according to the abnormal recessive allele the symbol is chosen.
- For example, the condition of albinism is characterized by the lack of melanin pigment in the skin, hair, eyes etc.
- This condition is a rare condition caused by the recessive allele in homozygous condition.
- The symbol in this case is 'a' for recessive allele and 'A' for the normal allele.
- Another method is followed in wild plant bacteria and viruses.
- When out of two phenotypes, one is more common in the population than its alternative form, it is referred to as the wild phenotype.
- The rare form is called the mutant phenotype.
- The symbol '+' is used to indicate the normal allele for

are evident of Mendel's approach.

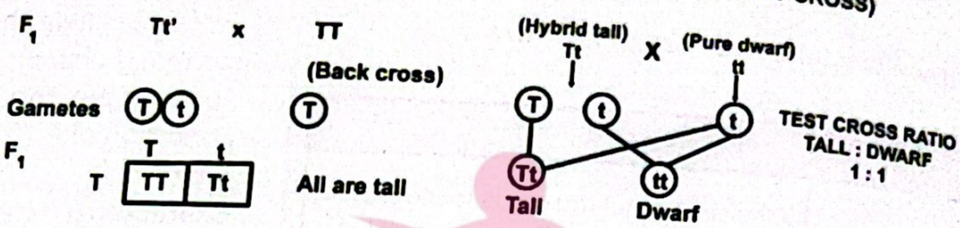
- The experiments performed by Mendel were elegant and his conclusions constitute foundation of the modern science of genetics. Mendel is therefore appropriately called, the **Father of Genetics.**

## BACK CROSS

- **The mating of a hybrid organism (offspring of genetically unlike parents) with one of its parents or with an organism genetically similar to the parent.**
- The backcross is useful in genetics studies for isolating (separating out) certain characteristics in a related group of animals or plants.

**BACK CROSS INVOLDING PURE DOMINANT PARENT (OUT CROSS)**

**BACK CROSS INVOLDING PURE RECESSIVE PARENT (TEST CROSS)**




## INHERITANCE OF TWO TRAITS (DIHYBRID CROSS)

- The inheritance of two traits simultaneously can be studied in **dihybrid cross** (a cross between two individuals, which are different on two traits).
- The two of the seven characters Mendel studied were seed **colour and shape**.
- Seeds shape may be either round (dominant) or wrinkled (recessive) and colour of the seed may be either yellow (dominant) or green (recessive).

### PROCEDURE AND OBSERVATIONS

- When he crossed a homozygous round yellow (RRYY) plant with homozygous wrinkled green (rryy) plant, in $F_1$ generation all the offspring were produced with both dominant phenotypes i.e., round yellow.
- In order to analyse the genotype of $F_1$ plants, he self-fertilized them and produced $F_2$ generation.
- He was expecting that dominant and recessive combinations would be produced in **3:1** in $F_2$ generation as he had obtained in monohybrid cross, but he observed that offspring were produced in four phenotypic combinations i.e., round yellow, round green, wrinkled yellow and wrinkled green in the ratio of **9:3:3:1**, The outcome of recombinant phenotype such as round green and wrinkled yellow, were surprising.

### INTERPRETATIONS OF THE RESULTS

- Based upon these observations, Mendel concluded that the $F_1$ offspring (round yellow) were dihybrid i.e., heterozygous (RrYy) for both traits.

wild type and the base letter is borrowed from the mutant type.

**KPK**

- Mendel's laws include the following three.

**LAW OF DOMINANCE**

- According to the law of dominance, different characters are controlled by units called factors, factors occur in pairs, of a pair, one factor dominates the other.

**LAW OF SEGREGATION**

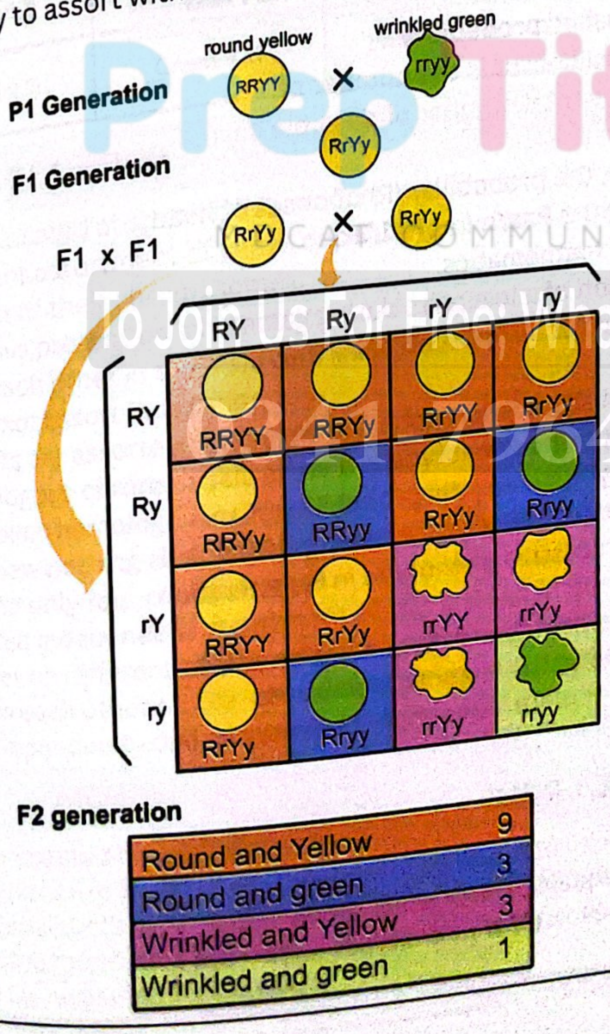
- It is also called as **law of purity of gametes.**
- According to it, in a heterozygote the dominant and recessive allele remain together without mixing with each other.

**BTB**

**LAW OF INDEPENDENT ASSORTMENT**

- This law applies only to those genes (allele pairs) located on different chromosomes (non homologous) or alternatively to genes that are very far apart on the same chromosome.
- This law explains

- The key incidence in the experiment happened when $F_1$ plants self-pollinated and produced F2 offspring.
- An $F_1$ plant can produce **four classes** of gametes (RY, rY, Ry, and ry) in equal quantities.
- If the sperms of the four classes are crossed with eggs of the four types, there will be **16 (4X4) equally probable ways in which the alleles can combine** in $F_2$ generation as shown in the Punnet square
- These combinations make up four phenotypic categories with a ratio of **9:3:3:1**.
- Mendel tested his seven pea characters in various dihybrid combinations and always observed as **9:3:3:1** phenotype ratio in F2 generation.
- The results of Mendel's dihybrid experiments are the basis of for what we now call **law of independent assortment**, which states that "**When two contrasting pairs of traits are followed in the same cross, each pair of alleles assort independently of other pairs of alleles during gamete formation**".
- Alleles of one pair inherit independently of alleles of the other pair.
- The distribution of alleles of one trait into gametes has no influence on the distribution of alleles of the other trait.
- Thus, the chance for a plant to be round or wrinkled is independent of its chance of being yellow or green.
- In other words, the alleles of each pair of contrasting traits have equal probability to assort with the alleles of other pair.




that desired characters of two parents can be expressed in single parents and undesired characters can be prevented from expression.

**SCOPE**

- The independent assortment genes also contribute in mutation because it results in the shuffling of chromosomes into various gametes.
- Crossing over occurs when homologous chromosomes exchange genetic information.
- Thus, chromosomes are formed that contain genes from both parents.

## LIMITATIONS OF LAW OF INDEPENDENT ASSORTMENT

- Although Mendel's work forms the basis of heredity, it does not cover all situations.
- The fact is that Mendel's work applies to diploid organisms, and not all organisms are diploid.
- Moreover, genes on the same chromosome could not be expected to assort independently.
- An offspring that inherited one trait would also inherit the other, unless crossing over occurred.
- Further, if genes are located on the X chromosome, the pattern of distribution in the succeeding generations is different.
- Males (because they have only one X chromosome - their other is Y and does not carry many of the genes) are more likely to show recessive X linked characters.

## USEFULNESS AND SCOPE OF INDEPENDENT ASSORTMENT

- Beside mutation and crossing over, independent assortment of traits is also a major source of variations in successive generations.
- It is only due to the crossing over and independent assortment of the traits that the characteristics may appear in new combination in next generation which often seems necessary for adaptations in varying environment.

## INHERITANCE AND MATHEMATICAL PROBABILITIES

- The chance to occur an event is called **probability**.
- The probability (P) that an event will occur is the number of favourable cases (a) divided by the total number of possible cases (n):**P= a/n**
- For example, when we toss a coin, the probability (P) of onset of head or tail (a) out of two possibilities (n) is **P=a/n** i.e., **P=1/2**
- Mendel had a firm background of mathematics.
- He understood that the segregation of allele pairs during gamete formation on the reforming of pairs at fertilization obey the rules of probability.
- Let us see how the rules of probability apply to inheritance.
- In genetics, the inheritance of a specific phenotype in a cross also has certain probability, like in monohybrid cross the probability of an offspring to inherit dominant phenotype in $F_1$ generation is **100%** and the probability of inheritance of recessive phenotype in $F_1$ generation is **0%**.
- Whereas probability of dominant phenotype in $F_2$ generation is **3/4** and probability of recessive phenotype in $F_2$ generation is **1/4**.
- The combined probability of two or more independent events can be calculated by product rule.

## PRODUCT RULE

- According to this rule the probability of round yellow phenotype in **F2** generation of a dihybrid cross is equal to the product of individual probabilities of round **(3/4)** and yellow **(3/4)** phenotypes i.e., **P = 3/4 x 3/4 = 9/16**

PTB

- When two independent events are occurring simultaneously like in dihybrid cross, the ratio of each joint phenotypic combination can be obtained by multiplying the probabilities of individual phenotypes.
- It is called product rule.
- The joint probability that both of the independent events will occur simultaneously, is equal to the product of individual probabilities of each event.

| Event No. 1 | Event No. 2 | Both events at a time |
|---|---|---|
| Seed shape | Seed colour | Seed shape and colour |
| Independent probability to be: | Independent probability to be: | Joint probability of being: |
| Round = ¾ | Yellow = ¾ | Round yellow = ¾ × ¾ = 9/16 |
| Round = ¾ | Green = ¼ | Round green = ¾ × ¼ = 3/16 |
| Wrinkled = ¼ | Yellow = ¾ | Wrinkled yellow = ¼ × ¾ = 3/16 |
| Wrinkled = ¼ | Green = ¼ | Wrinkled green = ¼ × ¼ = 1/16 |



## LINKAGE GROUP & INDEPENDENT ASSORTMENT

- Genes are located at specific loci on chromosomes.
- Independent assortment of genes depends upon independent assortment of their chromosomes.
- All the genes present on a homologous pair of chromosomes are linked to each other in the form of a linkage group.
- These cannot assort independently.
- Those traits are assorted independently whose alleles are riding nonhomologous chromosomes.
- Pea has seven homologous pairs of chromosomes.
- Mendel knew nothing about chromosomes. The traits he studied were confined to only four chromosomes.
- He reported independent assortment of those traits whose genes were either on different homologous chromosomes or were so far away from each other on the same chromosome that they appeared to assort independently due to crossing over.

## MENDEL PRESENTED HIS WORK

- Mendel presented his findings to Brunn Society for the study of Natural Science in **1865**.
- His work was published in the proceedings of the society in 1866.
- That laid the foundation of classical genetics.
- His work lay neglected for **34 years**.

- In 1900, 16 years after his death, three botanists; **Dutch botanist Hugo de Vries, De Correns of Germany and Tschmarck of Austria** independently rediscovered and acknowledged his work.

## EXCEPTIONS TO MENDELIAN INHERITANCE

- Since Mendel's time, our knowledge of the mechanisms of genetic inheritance has grown immensely.
- For instance, it is now understood that in how many different ways, alleles interact with their contrasting partner alleles at the same locus
- Relationships between the contrasting alleles at the same locus in heterozygous state are called **dominance relations.**
- Although Mendel had observed only one form of dominance relation **(complete dominance)** but later on many geneticists became able to explain several exceptions to the Mendelian inheritance that could not be explained on the basis of **complete dominance.**
- These exceptions are said to have non-Mendelian inheritance patterns. For example, incomplete dominance, co-dominance and multiple alleles.

**PTB**

- Dominance is a **physiological effect** of an allele over its partner allele on the same gene locus.
- There are four types of dominance relations among alleles, each indicating a different style of their functional effect upon each other.

## COMPLETE DOMINANCE



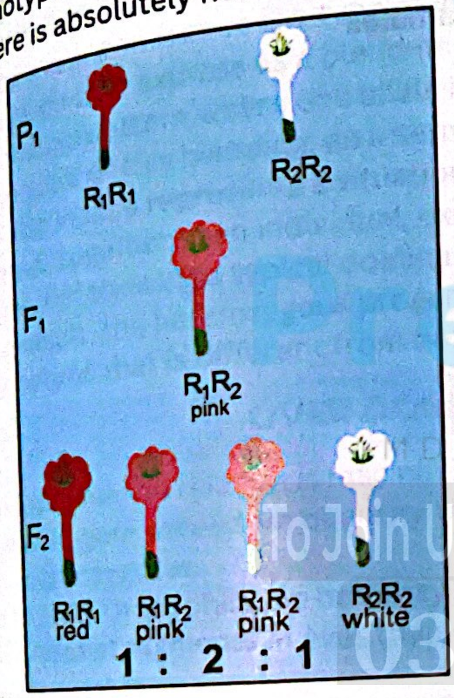
- When **one allele (R) is completely dominant over the other (r),** presence of the recessive allele is functionally hidden, so the heterozygote (Rr) has the same round phenotype as (RR) homozygote.
- The contrasting pairs of alleles for all the seven characters chosen by Mendel showed complete dominance.
- After Mendel, further breeding experiments were carried out on different plants and animals.
- Many novel phenotypes and phenotypic ratios were observed that could not be explained on the basis of complete dominance.

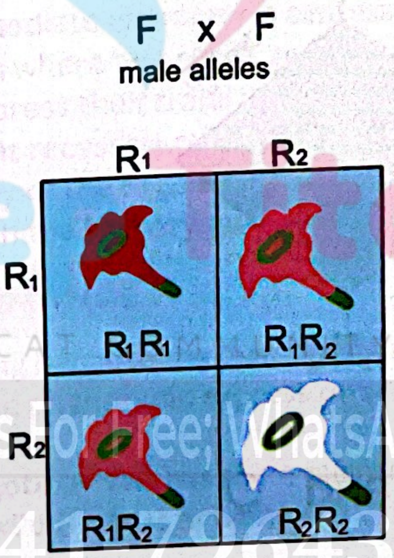


## INCOMPLETE OR PARTIAL DOMINANCE

- When the heterozygous has a phenotype that is intermediate between those of its two parents, the dominance relation between the parental genes is said to be incomplete dominance.
- Studies of the inheritance of many traits have shown that member of a pair of alleles may not be completely dominant to other.
- For example, red and white are common flowers in **Japanese four O'clock (Mirabilis Jalapa).**
- Each colour phenotype produces same phenotypes when these plants are self-pollinated.
- Without knowing, which is dominant, we might predict that all would have red flowers, or all would have white flowers.
- When he crossed a true breeding red flowered plant with a true breeding white flowered **4 O' clock**, all the **$F_1$ hybrids had pink flowers.**

- This new phenotype had a shade intermediate between those of the parents due to an intermediate amount of pigment in petals.
- In 1899 this cross was first made by German botanist **Carl Correns**, who found that all **F1** offspring have pink flowers.
- When two of these pink flowered plants are crossed, red flowered, pink-flowered and white-flowered offspring appear in a ratio of **1:2:1**.
- Allele for red is designated as **$R_1$**, and the allele for white as **$R_2$**.
- Red was homozygous for red alleles **($R_1R_1$)** and white was homozygous for white alleles **($R_2R_2$)**. But when the allele for red and allele for white were present together in the same plant, neither of them masked the effect of the other; rather these alleles showed **incomplete dominance in the form of pink colour ($R_1R_2$)**.
- The pink-flowered plants are clearly the heterozygous individuals and neither the red allele nor the white allele is completely dominant.
- Punnett square indicates that the phenotypic ratio is the same as the genotypic ratio.
- There is absolutely no need of a test cross.





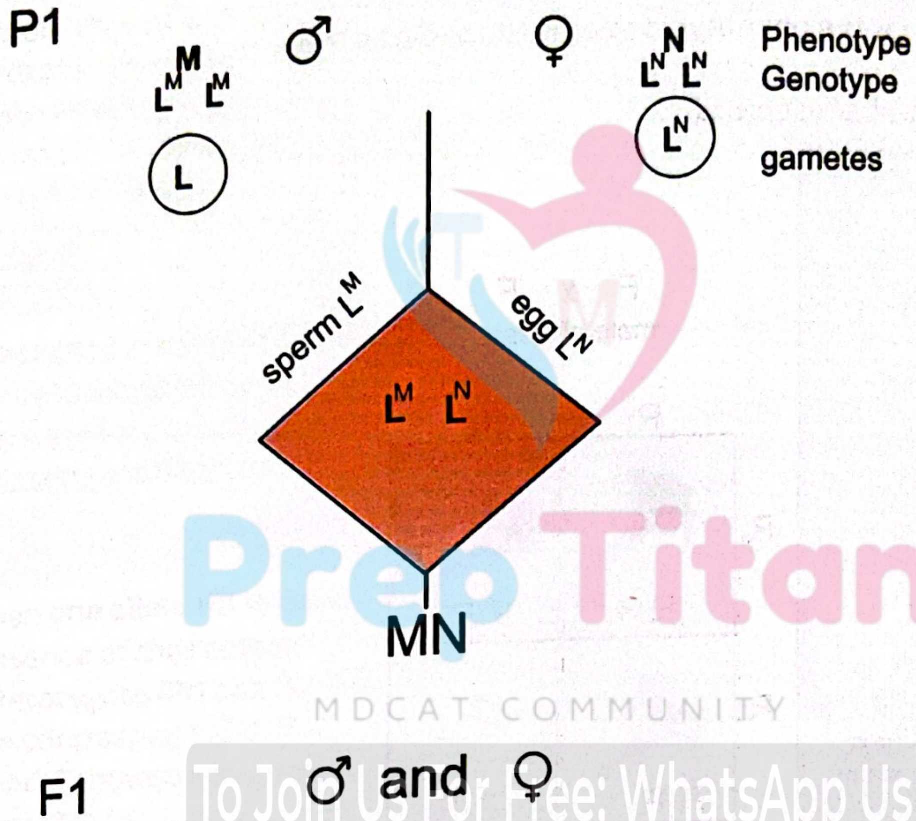

**PTB**

- The flower colour does show blending at phenotypic level in **F1**, which is quite contrary to what Mendel observed.
- But the re-appearance of red and white flowers in **F2** confirms that blending does not occur at genetic level.

## CO-DOMINANCE

- Another variation on dominance relationships between alleles is called co-dominance, in which both contrasting alleles at the same locus express independently without influencing each other, so the phenotype of both the alleles become apparent.
- **For example**, AB blood group and MN blood group.
- The human **MN blood group** is determined by two co-dominant alleles ($L^M$ and $L^N$) for two specific molecules located on the surface of red blood cells, the M and N molecules.

- A single gene locus at which two allelic variations are possible determines the phenotypes of this blood group.
- Individual homozygous for LM allele ($L^ML^M$) have red blood cells with only M molecules
- Individuals homozygous for $L^N$ allele ($L^NL^N$) have red blood cells with only N molecules: but both M and N molecules are present on the red blood cells of individuals heterozygous for M and N alleles ($L^ML^N$).
- When the dominance is not complete, the capital case and small case letters will not be used to represent the genes, instead, only capital case letter differentiated by **numeric figures** will be used to represent the phenotypes.






- In case of co-dominance phenotype of the heterozygote is distinct in quality from those of the two homozygotes. It is **not an intermediate quantitative expression** like incomplete dominance. Each allele of the gene pair is associated with a different substance.

**PTB**

- Human blood groups can be of many types, e.g. ABO, MN, MNSs, Rh etc.
- Landsteiner and Levine discovered MN blood types in man on the basis of specific antigens present on RBC.
- These RBC antigens induce production of their specific antibodies.
- There are three general phenotypes: M, N and MN.
- M phenotype has antigen M which is produced by gene $L^M$.
- N phenotype has antigen N that is produced by its allele $L^N$.
- MN phenotype has both M and N antigens, simultaneously produced by their alleles $L^M$ and $L^N$.

| Phenotype | Genotype | Antigens on RBC |
| --- | --- | --- |
| M | $I^MI^M$ | M |
| N | $I^NI^N$ | N |
| MN | $I^MI^N$ | M and N |

- If a man of M blood group marries a woman of N blood group, all their children will have MN blood group.

**PTB**

- Many patterns of inheritance which cannot be explained on the basis of Mendel's laws alone were discovered in plant and animals.
- Such patterns of inheritance are described as non-Mendelian inheritance.
- Incomplete dominance is a type of interaction where both the alleles of a given trait express as a blend (mixture) as against a normal Mendelian pattern where one allele is dominant over the other.
- As a result of this blending, an intermediate character is expressed.
- Co-dominance represents a situation where two allelic genes when present together in an individual, express their traits independently instead of showing a typical dominant recessive relationship.
- As a result, the heterozygous progeny of the $F_2$ generation shows a phenotype that is different from both the homozygous parents.

## OVER DOMINANCE

- This dominance relation is fascinating because the over dominant heterozygote exceeds in quantity the phenotypic expression of both the homozygotes.
- In fruit fly Drosophila the **heterozygote (w+/w)** has more quantity of **fluorescent pigments** in eyes than **wild (w+/w+)** or **white eye (w/w)** homozygotes.

## MULTIPLE ALLELES

- So far, we have discussed inheritance patterns involving only two alleles per gene.
- But many genes have more than two alleles which are called multiple alleles.
- Multiple alleles are produced **by gene mutation**.
- All the multiple alleles of a trait occupy the same locus.
- Some traits may be controlled by as many **as 100 or more multiple alleles** but each individual carries only two of them as each locus is twice represented in a diploid individual.
- For example, if a trait is controlled by **3 multiple alleles** i.e. **A1**, **A2** and **A3** but every individual carries any two of them like **A1A1**, **A1A2**, **A1A3**, **A2A2**, **A2A3** or **A3A3**.
- The **ABO blood groups** in humans are one example of multiple alleles

**BTB**

- There is no crossing over between the members of multiple alleles.
- Crossing over takes place between two different genes only and does not occur within gene.
- **ABO antigens** are **glycolipid** in nature.
- Beside their presence on red blood cells, soluble antigens can be present in plasma, saliva and other secretions.
- These antigens are also expressed on tissues other than red blood cells.
- An **Erythroblast** is a type of RBC which still retains a cell nucleus.
- It is intermediate precursor of normal erythrocytes.

### Genetic Analysis

- Genetic analysis based on blood groups helps in **solving cases of disputed parentage**.
- It can only be used to prove that an individual is not the parent of a particular child,
- **E.g.** a child of AB phenotype ($I^A I^B$) cannot be the child of a parent of phenotype O (ii).
- Similarly, a man of B phenotype cannot

**PTB**

- Some genes may have as many as **300 alleles**.
- All such altered **alternative forms** of a gene, whose number is more than two, are called multiple alleles.
- Any two of these multiple alleles can be present in the genome of a diploid organism, but a haploid organism or a gamete can have just one of them in its genome.

be father of a blood type A child, whose mother is of phenotype O.
His father could either be A or AB phenotype.

## BLOOD GROUP SYSTEMS

- There are a number of different blood group systems found in human.
- The International Society of Blood Transfusion has recognized up to **30 major blood group systems**.
- These systems are characterized by the presence or absence of specific molecules, called A**ntigens that are situated on the surface of the red blood cells**.
- Most antigens are glycoprotein molecules.
- Two main blood group systems are **ABO system and Rh (Rhesus) system.**
- These two systems are more significant because incompatibility between donor and recipient's blood with respect these two systems may become dangerous to life.
- There are more than **two hundred minor blood groups** (belong to the rest of blood group other than ABO and Rh systems) that usually do not complicate the blood transfusions. These are known as **rare blood types**.
- One example of such blood group systems other that " ABO and Rh" is already given in co-dominance in the form of **MN blood** group system.



### ABO BLOOD GROUP SYSTEM

- A well-known example of multiple alleles is the ABO blood group system in humans.
- Karl Landsteiner discovered it in 1901.
- ABO blood groups are also found in many other primates such as apes, chimpanzees, bonobos, and gorillas.



## ANTIGENS OF ABO SYSTEM

- There are several surface markers on the RBC membrane, which are generally called **antigens**.
- ABO system has four different phenotypes which is based upon two antigens present on the surface of RBC i.e., **A** antigen and **B** antigen which are **glycoprotein in nature**.
- If A antigen is present on the surface of RBC, the blood group is called type A and if B antigen is present, the blood group is called type B.
- If both antigens are present, the blood group is type AB and if none of these are present the blood group is type O.
- ABO Blood type antigens are not present only on the surface of red cells.
- They are also normally secreted by some people in their body fluids including saliva, tears and urine.
- Such persons are called **Antigen Secretors**

- Whether someone is able to secrete them is generally controlled by a dominant **secretor gene "Se"** present on **chromosome 19**.

## GENETIC BASIS OF ABO SYSTEM

- Bernstein explained the genetic basis of ABO system in **1925**.
- ABO blood group is controlled by autosomal single **polymorphic gene** I (which stands for Isohaemagglutinogen) on **long arm of chromosome 9.**
- The four blood types result from various combinations of three different alleles, symbolized as **$I^A$ (for the ability to make substance A) $I^B$ (for B) and i (for neither A nor B)**.
- Their dominance relations are very interesting, alleles $I^A$ and $I^B$ are completely dominant over the allele i, while they are co-dominant to each other because each expresses in equallyin heterozygous ($I^AI^B$) state to produce AB phenotype.
- Therefore, $I^AI^A$ or IAi genotypes will producee phenotype A.
- Similarly, $I^BI^B$ or $I^Bi$ produces phenotype B.
- The homozygous ii will produce phenotype O.
- IAIB produce AB phenotype.
- The blood groups alleles start their expression at early **embryonic stage** and keep on expressing themselves till death.
- Therefore, the blood group phenotype of a person never changes throughout life.

## ANTIBODIES OF ABO SYSTEM

- It has been observed that if wrong transfusion is carried out, the recipient's blood start **Agglutination** (antigen-antibody reaction) and clumping occurs.
- This is due to the presence of antibodies against wrong antigen.
- Anti-A and anti-B antibodies appear in plasma during the first few months after birth.
- These antibodies are produced in the absence of their corresponding antigens.
- For example, those with **type A** blood have **anti-B antibody** in their plasma.
- Similarly, **type B** people have **anti A antibody** and those with **type AB** blood have **no anti A** or **anti B antibodies** in their plasma.
- Type O individuals have no antigens but have **both anti A and ant B antibodies** in the plasma.
- These antibodies of ABO system do not require any stimulus to produce their production begins from embryonic life and remains continue throughout life.

## TRANSFUSION PRINCIPLE

- When transfusions are carried out between two incompatible (different) blood groups antigens of donor react with the antibodies (also called agglutinins) of the recipient, then the red blood cells clump with one another.
- The clumping of red blood cells is known as agglutination.
- Therefore, the transfusions are carried out based on **donor's antigens and recipient's antibodies.**

**BTB**

- **Blood transfusion** is the process of transferring blood into one's circulation **intravenously**.
- Transfusions are

- Due to these limitations the persons with type A blood group can receive blood from type A or from type O because they have anti B antibody so they cannot be given any blood carrying B antigen
- Similarly, the persons with type B blood group can receive blood from type B or from type O but those with type AB blood group can receive any blood since they do not have antibody to react with donor's blood, hence they are called **universal recipient**.
- The persons with type O blood group can receive blood only from type O because they have both antibodies that can react with any antigenic blood (type A, B or AB) but they can donate to any one as they do not have any antigen to interfere with recipients' blood. Therefore, they are called **universal donor**.

| Blood Group | Genotype | Antigen on RBC | Antibody in Plasma | Can Donate Blood To | Can Receive Blood From |
|---|---|---|---|---|---|
| A | $I^AI^A$ (homozygous), $I^Ai$ (heterozygous) | A | B | A, AB | A, O |
| B | $I^BI^B$ (homozygous), $I^Bi$ (heterozygous) | B | A | B, AB | B, O |
| AB (Universal Recipient) | $I^AI^B$ (heterozygous) | A & B | None | AB | A, B, AB, O |
| O (Universal Donor) | ii (homozygous) | None | A & B | A, B, AB, O | O |

**PTB**

- Any blood transfusion is ideally safe if it does not cause agglutination in the recipient.
- Agglutination leads to serious results because clumped cells cannot pass through fine capillaries.
- The blood samples of the donor and the recipient are cross matched for compatibility before giving transfusion.
- If incompatible blood is transfused, dangerous haemolytic reaction occurs.
- Either the antibodies of the recipient destroy the RBC of donor or the antibodies of the donor haemolyze the RBC of the recipient.
- Phenotype O can also be used as donor for small transfusions to A, B and AB recipients because donor's antibodies are quickly absorbed by other tissues or greatly diluted in the recipient's blood stream.
- The blood serum containing antibodies is called **antiserum**.

**FTB**

- **Aprotinin** is a drug that is given prior to heart surgery to reduce the risk of bleeding and the need for transfusion
- One unit of blood can save three lives rather than one.
- Blood group allele i is most frequent in the population.

## RH BLOOD GROUP SYSTEM

- The Rh blood group system is clinically the most important blood

used for various **medical conditions** such as deficiency of blood, blood loss during pregnancy or any surgery, any blood cell disease like thalassemia, sickle cell and leukaemia etc.

**BTB**

- We inherit half of our genes (alleles) from mother, & the other half from father, so we end up with two alleles for every trait in our **phenotype**.
- Examples of blood group systems other than "ABO" and "Rh" are MNS, P, Lutheran, Kell, Lewis, Duffy, Kidd, Diego, etc.
- Rh blood group system currently consists of **50** defined blood group antigens, among which the 5 antigens **D, C, c, E, and e** are the most important ones.
- The Rh factor is notorious in cases where antibodies produced by a pregnant woman react with the red blood cells of her developing **foetus**.
- The situation arises when Mother is **$Rh^-$** but foetus is **$Rh^+$**, having inherited the factor from father.

group system after ABO.

- The name of this system (Rh) is derived from **Rhesus monkey**, because its antigen was first discovered in it by **Landsteiner in 1930s**.

## ANTIGENS OF RH BLOOD GROUP SYSTEM

- This blood group system is characterized by the presence or absence of **"D" antigen also called Rh factor**.
- If Rh factor is present, then persons are called Rh positive and if it is absent then they are called **Rh negative**.
- The D antigen incompatibility between donor and recipient can cause problem not only during blood transfusion but it is also a relevant cause of **haemolytic disease of the newborn** or **erythroblastosis foetalis**.

## GENETIC BASIS

- This blood group system is mainly controlled by "D" gene which determines the formation of D antigen or Rh factor, while its alternative allele "d" inhibits the formation of Rh factor.
- D is completely dominant over d, therefore, persons having genotypes DD or Dd have D antigen (Rh factor) on their RBC and are Rh positive.
- Persons with genotype "dd" do not have Rh factor and are Rh negative.

| Blood Group (phenotype) | Rh- Antigen / Factor | Genotypes | Anti Rh-Antibody | Transfusions |
|---|---|---|---|---|
| $Rh^{+ve}$ | Present | DD or dd | Not produced | $Rh^{+ve}$, $Rh^{-ve}$ |
| $Rh^{-ve}$ | Absent | dd | Produced (if stimulated) | $Rh^{-ve}$ |

- **The blood group O- (O negative)** is actual universal donor because it has no antigen of ABO system and of Rh system which can interfere with recipient's blood,
- **Whereas AB+ is Actual universal recipient** because it has neither anti-A and anti-B nor anti-Rh antibodies, therefore, it cannot resist any donor's blood.



## ANTI RH-ANTIBODY & TRANSFUSION PRINCIPLE

- Rh blood group system also has a mechanism of antibody production i.e., anti-Rh antibody. which is produced in Rh negative blood.
- Unlike ABO antibody production mechanism, the production of anti Rh antibody is different in the sense that it always requires a stimulus in the form of exposure to Rh factor for its production
- A Rh-negative person does not produce anti-Rh antibodies unless he is exposed to Rh antigen
- Rh positive donor is totally incompatible for Rh negative recipient.
- If Rh negative person receives an Rh antigen through wrong Rh positive blood transfusion, he will begin to produce anti-Rh antibodies against Rh antigens.
- Once the mechanism of anti-Rh antibody production is stimulated, then it remains continue for whole life.
- Rh negative blood, clear of any anti-Rh antibody from a donor who

**BTB**

- Rh blood group is encoded by three genes C, D and E.
- These genes occupy two loci i.e. locus D and C or E loci.
- Gene D is located on D locus while the gene C or E located on another locus.
- D locus is of prime importance.

The positive blood groups can receive all times negative blood groups while negative blood groups can only receive one-time positive blood group but not second time.

has never been exposed to Rh antigen can be transfused to Rh positive recipient.

## ERYTHROBLASTOSIS FOETALIS

- Erythroblastosis foetalis develops in a foetus, when anti-Rh antibodies produced by the mother pass through the placenta.
- Maternal-foetal Rh incompatibility results when an **Rh$^{-ve}$** woman, married to an **Rh$^{+ve}$** man conceives a child who is **Rh$^{+ve}$**.
- If the man's genotype is DD, all of their offspring (Dd) will be **Rh$^{+ve}$**.

## MECHANISM

- If the man's genotype is Dd, half of their offspring with Dd genotype will be Rh+.
- If RBC of Rh+ foetus cross the placental barrier and enter into Rh- mother's blood stream, the mother's immune system reacts to the foetal Rh antigen stimulus by producing a large number of anti - Rh antibodies.
- When mother's anti - Rh antibodies seep through placenta into blood circulation of foetus, they start haemolysis (break down / bursting) of RBC of foetus. As this destruction continues, the foetus becomes anaemic (weak due to deficiency of blood).

## EFFECTS OF THE PROBLEM

- The anaemic foetus starts to release many -immature erythroblasts into his blood stream.
- That is why this haemolytic disease of the new born is called erythroblastosis foetalis.
- This anaemia may lead to abortion or still birth.
- Even if the pregnancy continues, the liver and spleen of the foetus swell as they rapidly produce RBC.
- The **breakdown product of RBC** called **bilirubin** also accumulates in the foetus.
- Bilirubin damages his brain cells and turns his skin and whites of the eye yellow. This condition is **jaundice**.
- So, the baby if born alive, suffer from severe haemolytic anaemia and jaundice.
- Such baby's blood should be immediately replaced by **Rh$^{-ve}$** blood free of anti - Rh antibodies.
- Later, Baby will develop **Rh$^{+ve}$** blood himself.



## DEGREE OF RISK

- The first Rh incompatible pregnancy may not face many problems if very few of foetal antigens cross placenta into maternal circulation and the amount of maternal antibody production is not very high.
- But when placenta detaches at birth, a large number of foetal cells enter mother's blood stream and stimulate production of large amount of anti - Rh antibodies by the mother.
- These anti - Rh antibodies persist in mother's blood for a long time and are persistent risk for the next Rh+ foetus.

## TREATMENT

- Sensitization of $Rh^{-ve}$ mother is avoided by a simple therapy.
- She is given an **injection of Rh antiserum** during early pregnancy (1st trimester) and immediately after birth within 72 hours of delivery.
- The Rh - antibodies in the Rh antiserum will **destroy $Rh^{+ve}$ RBC** of the foetus before they stimulate production of maternal anti - Rh antibodies.
- The injected antiserum disappears before the next pregnancy.
- This must be done with each pregnancy whether it ends in a delivery of an abortion.
- Sometimes a **mild ABO incompatibility** protects the baby against a more severe Rh incompatibility.
- If $O^{-ve}$ mother conceives A+ or B+ baby, any foetal A or B type RBC entering the mother's blood are quickly destroyed by her anti - A or anti - B antibodies, before she can form anti - Rh antibodies.

## PLEIOTROPY

- When a single gene affects two or more traits, the phenomenon is called pleiotropy.
- Such a gene with **multiple phenotypic effect** is called **pleiotropic gene.**
- **Examples:**
  1. White eye gene in Drosophila also affects the shape of sperm storing organs (spermathecae).
  2. Genes that affect growth rate in humans also influence both weight and height.
  3. In cats, the dominant allele W not only makes fur pure white but also causes deafness.
- In ww homozygous normal pigmented cats, melanocytes produce pigment of fur and also contribute to 'hear cells in inner ear that sense sound.
- When a cat gets W allele, its melanocytes fail to develop properly.
- Melanocyte failure causes both phenotypes, i.e. white fur and deafness.

## GENE INTERACTIONS

- During the study of Mendelian experiments, you have learnt about the phenomenon of dominance which is an interaction between the contrasting alleles of the same locus.
- Now you are going to understand the interaction between the alleles of different gene pairs located on different loci of same or different chromosomes.
- These are known as **non-allelic interactions** or **inter-genic interactions**.

## EPISTASIS

- Epistasis is composed of Greek roots that means **"standing upon"**.
- An example of nonallelic interactions is epistasis, which can be defined as the phenomenon in which the **effect caused by the genes at one locus interferes with or hides the effect caused by another gene at another locus**.
- In such interactions, the gene which suppresses or masks the effect of

**BTB**

- The term gene was introduced by **Wilhelm Johansson** (Danish botanist and geneticist) in **1909**.
- Gene is a small **segment of DNA** as chromosome.
- It consists of a **specific sequence of nucleotides** which code a specific protein or polypeptide chain.
- During the formation of gametes, the homologous pairs of chromosomes exchange their segments. This process is called crossing over.
- When these alleles distribute in gametes, a wide variety of gametes are produced. This is why the siblings are not identical.
- The cross-over data may also be used to determine the location of gene on chromosome i.e. gene mapping.

action of a gene at another locus is known as **epistatic gene** or **inhibiting gene** and the gene which is suppressed is known as **hypostatic gene.**

- Epistasis must not be confused with dominance. Dominance is the relationship between alleles of the same gene occupying the same locus, but epistasis is the interaction between different genes occupying different loci.

| Dominance | Epistasis |
|---|---|
| 1. It involves a single pair of alleles. | 1. It involves two pairs of alleles. |
| 2. A gene suppresses the expression of its own allele. | 2. A gene suppresses the expression of an allele of another gene. |
| 3. Only the recessive allele is suppressed. | 3. It suppresses the effect of both dominant and recessive alleles of another gene. |
| 4. The effect is only due to the dominant allele. | 4. Both dominant and recessive alleles can become epistatic. |

**Relationship of epistasis with polygenic inheritance:**

- Both epistasis and polygenic inheritance involve interaction of more than one gene.
- The distinction between the two phenomena is that in epistasis the traits show discontinuous variations whereas, in polygenic inheritance the traits show continuous variations in the population.

**DO YOU KNOW?**

- This blood phenotype was first discovered in Bombay, now known as Mumbai, in India, by Dr. Y.M. Bhende, as published in 1952. It is present in about 0.0004% (about 4 per million) of the human population generally, though in some places such as Mumbai (formerly Bombay) local populations can have occurrences in as much as 0.01% (1 in 10,000) of inhabitants.

## EXAMPLES OF EPISTASIS



- In animals, examples of epistasis are Bombay phenotype and coat color in the Labrador retriever.
- In plants, examples of epistasis are inheritance of flower color (pigment phenotype) of sweet pea (Lathyrus odoratus).

## BOMBAY PHENOTYPE



- The expression of ABO blood type antigens by $I^A$ or $I^B$ gene depends upon the presence of another **gene H**.
- ABO locus is on chromosome **9**, while **H locus** is on chromosome **19**.
- H gene changes a precursor substance into substance H. It produces an enzyme that inserts a sugar onto a precursor glycoprotein on the surface of RBC.
- The H substance is a precursor to the A and B antigens.
- Only then **antigen A** or **antigen B** specified by $I^A$ or I gene could attach to this sugar of substance H.
- The **recessive allele h** cannot insert sugar molecules to glycoprotein.
- Therefore, **hh** individuals lack the site of attachment for antigen A or antigen B.
- Thus, A and B antigens cannot adhere to their RBC and fall away.
- Their RBC lack A and B antigens although they do not lack $I^A$ or $I^B$ genes.
- They are phenotypically like O, but are not genotypically O. Their phenotype is called **Bombay phenotype** (called so because first described in that Indian city).

BTB

- Coat colour in Labrador retriever (a highly popular type of dog) is an excellent example of epistasis in animals.
- They have coats of three basic colours:
  I) yellow II) black III) chocolate.
- The allele for black coat colour (B) is dominant to the chocolate colour (b).
- Therefore, a puppy will only be chocolate if each parent contributes the chocolate alleles (bb).
- If one (Bb) or both (BB) parents contribute the black (dominant) gene, the puppy will be black (BB or Bb).
- The gene that determines yellow coat colour is at a different location (locus) in the DNA from the black versus chocolate gene.
- In order to be yellow, a Labrador must have two recessive copies of the yellow gene (ee).
- In this case, the yellow colour genes become epistatic and completely inactivate the black or brown genes, and the puppy is yellow. This means both parents contributed a yellow gene (e).
- However, if only one (Ee) or no (EE) yellow genes are contributed, the puppy will be either black or chocolate, determined as explained above by what is on the black/chocolate gene.
- Two yellow Labradors (ee) can only have yellow puppies (ee) since they both have two copies of the yellow gene, and that is all they can contribute.
- If a black Labrador, homozygous for both gene pairs (BBEE), is crossbreed with a yellow (bbee) partner, all the offspring will be black (BbEe).
- If such black Labradors, heterozygous for both gene pairs (BbEe), are interbred, all three coat colours (black, chocolate, and yellow) are expected in offspring in a **9:3:4 ratio**.

## GENE LINKAGE

- Mendel didn't know anything about the physical nature of genes or that genes are part of chromosomes, because nature of chromosomes were not even discovered until long after his experiment were concluded.
- The number of genes in a cell is far greater than the number of chromosomes, in fact **each chromosome has hundreds and thousands of genes**.
- Genes located on the same chromosome that tend to be inherited together in genetic crosses are said to be **linked genes**.
- **The phenomenon of staying together of more than one gene on the same chromosome is called gene linkage.**
- If genes are linked on autosomes, their linkage is called **autosomal linkage**.
- Similarly, if they are linked on sex chromosome, their linkage is called **sex linkage**.
- All the linked genes found on the same homologous pair of chromosomes form a group, known as **linkage group**, so the number of linkage groups in an organism are equal to the number of homologous

BTB

- **SRY Gene**
  Located on the Y chromosome, encodes a **transcription factor protein** which controls expression of other genes.
- It stimulates male development i.e., developing testes, secrete anti-Müllerian hormone, and destroy female structure.
- Testosterone hormone develops the male structure.

BTB

**Linkage**

- It keeps the genes together.
- It involves individual chromosome.
- It reduces variability.
- It provides higher frequency of parental type in test cross progeny.

**Crossing Over**

- It leads to separation of linked genes.
- It involves non-sister chromatids of homologous chromosomes.
- It increases variability.
- It provides equal frequency of parental and recombinant type in test cross progeny

pair of chromosomes in that organism.

- The linked genes tend to be inherited together (en bloc inheritance) in the offspring, so usually they do not show recombination and do not assort independently in the offspring.
- So, the ideal **Mendelian ratio of independent assortment** is deviated.

## DETECTION OF GENE LINKAGE

- Gene linkage can easily be detected by performing a **test cross** between two gene pairs (dihybrid test cross).
- In such type of test cross, a heterozygous individual for two traits (F1) is **back crossed** with its recessive parent (P).
- If all four phenotypic combinations (parental and recombinants) are produced in equal **1:1:1:1 ratio**, then there would be **no linkage** between the genes.
- If this ratio is deviated ie.more parental types and less recombinant types, this indicates the **incomplete or partial linkage,** but if only parental types are produced, complete or tight linkage is believed.
- In a typical dihybrid cross, the complete or tight linkage inhibits the outcome of recombinant types and disturbs **9:3:3:1** ratio of independent assortment, as a result, only parental combinations are produced in **3:1**.
- To see how linkage between genes affects the inheritance of two different characters, let's take an example from **T. H. Morgan's experiments on Drosophila**.



## MORGAN'S EXPERIMENT

- T. H. Morgan studied about **85 pairs of contrasting traits** in fruit fly **Drosophila melanogaster**.
- Two of them were wing length and width of the abdomen.
- Allele for **long wings (Vg)** is dominant over **short or vestigial wing (vg)**.
- Similarly, allele for **broad abdomen (A)** is dominant over **narrow abdomen (a)**.
- Morgan crossed a fly with long wings and a broad abdomen with one having vestigial wings and a narrow abdomen.
- The $F_1$ offspring all had long wings and broad abdomens.
- Then two of these flies were mated. In the **$F_2$ generation** about ¾ of the offspring had long wings and a broad abdomen, and nearly all the remaining flies (about ¼ of the total) had vestigial wings and a narrow abdomen.

**Gene linkage encounters independent assortment:**

- Morgan's results were very different from the results he expected based on the law of independent assortment, i.e., **9:3:3:1**.
- From his data, Morgan concluded that the genes for abdomen width and wing length were located on the same chromosome, so they did not assort independently during meiosis.
- Instead, they inherited together. Therefore, no recombinant types were produced, and the standard ratio of independent assortment **9:3:3:1** is modified to **3:1**.

- In crossing over, the exchange of maternal and paternal chromatid parts occurs while homologous chromosomes are paired during prophase of meiosis I.
- Let's recall **Morgan's experiment** in which a female fly having grey body and normal wings was crossed by a male fly having black body and vestigial wings.
- Although most of the eggs had a chromosome with either the **$b^+vg^+$** or **b vg** parental genotypes for body colour and wing size, but some eggs had a recombinant chromosome with $b^+$ vg or b $vg^+$ genotypes.
- Fertilization of these various classes of eggs by homozygous recessive sperms (b vg) produced an offspring population in which **17%** exhibited non-parental, recombinant phenotypes. These recombinants were the products of crossing over.

PTB

- Gene linkage is a physical relationship between genes.
- Man has 23 linkage groups.
- Genes for colour blindness, haemophilia, gout etc. form one linkage group on human X-chromosome.
- Similarly, genes for sickle cell anaemia, leukemia and albinism make another linkage group on human chromosome 11.
- Linked genes whose loci are close to each other do not obey Mendel's law of independent assortment, because these cannot assort independently during meiosis.
- Gene linkage also minimizes the chances of genetic recombination and variations among offspring.

FTB

**Effect of number of progenies on detection of linkage:**

- Gene linkage could be observed or evaluated only if the number of progenies is quite large because probability is used to determine the kinds of gametes produced and the chances of their combining.
- The larger the number of individuals, the greater is the likelihood that the laws of probability will hold.
- A small sample may not produce the results indicated by the laws of probability.
- Linkage can be recognized when an excess of parental type offspring and fewer recombinant types are observed, deviating from the expected Mendelian ratios.

## CROSSING OVER

- Linked genes can be separated by crossing over.
- The closer the two gene loci, the more strongly their genes are linked.
- The farther apart two genes lie, the greater are chances of their separation through crossing over.
- Crossing over is an **exchange of segments between non-sister chromatids of homologous chromosomes during meiosis.**
- Let us visualize crossing over by considering only one pair of homologous chromosomes.
- The homologous chromosomes pair up lengthwise, point to point and locus to locus.
- One homologue carries genes 'A' and 'B', the other homologue has 'a' with 'b'.
- **Chiasmata** are formed at many places between non-sister chromatids of homologous chromosomes.
- Crossing over occurs at **4-strand stage** between non-sister chromatids.
- It may take place at more than one place along a chromosome.
- Exchange of chromosome segments logically means exchange of DNA, i.e. genes or alleles.
- As alleles of non-sister chromatids are different, an exchange between their segments results in recombination of genes.
- Allele 'b' crosses over to homologue containing allele 'A'; and allele 'B'

KPK

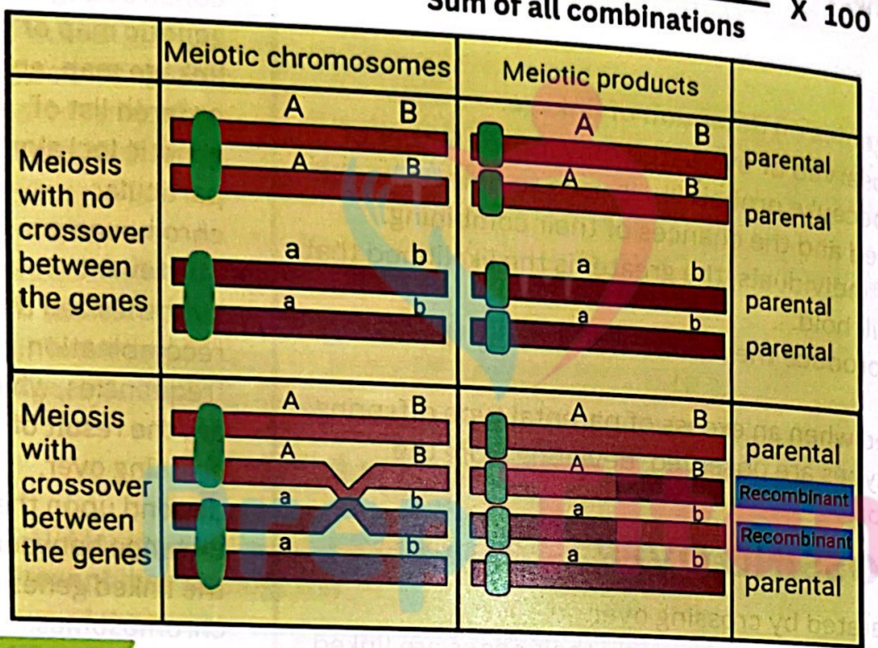
**TEXT TEXT INCREASES METABOLISM TO**

- Discovery of linked genes and recombination due to crossing over led one of Morgan's students, **Alfred H.** Sturtevant, to a method of constructing a **genetic map or linkage map**, an ordered list of genetic loci along a particular chromosome.
- **Sturtevant** hypothesized that recombination frequencies, which are the result of crossing over, depend upon the distance between the linked genes on chromosomes.
- So, he assumed that the farther apart two genes are, the higher the probability that a crossover will occur between them and therefore the higher the recombination frequency.
- Using recombination data from various fruit fly crosses, Sturtevant assign relative positions of several genes along the length of chromosome. Sturtevant's linkage

comes on the homologue of 'a'.

- Then homologous chromosomes separate by opening up chiasmata.
- The sister chromatids also separate from each other, and each becomes an independent chromosome to move singly in each of the four haploid gametes.
- **Four types of gametes** are formed: two with parental combinations of linked genes, i.e. AB and ab, and two with recombination of genes, i.e. Ab and aB.
- If crossing over does not occur, only the two parental types of gametes are formed.
- Parental types of gametes produce parental types of offspring, while recombination gametes produce recombinant types of offspring.

$$\text{Recombination frequency} = \frac{\text{Recombination types}}{\text{Sum of all combinations}} \times 100$$




PTB





## CROSS OVER OR RECOMBINATION FREQUENCY

- It is the **proportion of recombinant types** between two gene pairs as compared to the sum of all combinations.
- The recombination frequencies between two linked genes can be **calculated by backcrossing heterozygote to a homozygous double recessive.**
- The recombination frequency is **directly proportional to the distance between the linked gene loci.**
- Genes can be mapped on a chromosome based on their recombination frequencies.
- If **1%** of recombination frequency is equal to **1 unit map distance**, the two linked genes A and B with a **20%** recombination frequency must be **20 units apart.**
- Crossing over **produces genetic variation** among offspring.
- Genetic variations lead to tremendous variations in their traits.
- Variations provide raw material for evolution by letting them adapt successfully to the changing environment.

map three genes include: the **body colour (b)**, **wing size (vg)**, and a third gene, called **cinnabar (cn)**.

- Cinnabar is one of many Drosophila genes affecting eye colour.
- Cinnabar eyes, a mutant phenotype, are a brighter red than the wild type colour.
- The recombination frequency data is given below:
  **Cn-b=9%**
  **cn-vg=9.5%**
  **b-vg=17%**
- With the help of these data, the only assumption about the location of these three genes can be made is that **cn is located midway to the b & and vg.**
- Sturtevant expressed the distances between genes in map units.
- The map units are arbitrary, so they are not related to any physical units of length, however, one map unit is supposed to equal to **1%** recombination frequency.
- Today map units are often called centimorgans (CM) in honor of Morgan.
- The **b-vg** recombination frequency **(17%)** is

FTB

- Percentage of crossing over or recombinant frequency has helped in locating the genes on chromosomes, determining their sequence and preparation of chromosomal maps.

## SEX LINKAGE IN DROSOPHILA

- Thomas Hunt Morgan **(1910)** provided experimental evidence in support of chromosomal theory of heredity through discovery of sex linkage in **fruit fly Drosophila.**
- **Drosophila is a very useful organism for genetic studies for many reasons:**
- The tiny fly is often seen hovering over rotten fruits.
- It can be easily collected and cultured on mashed banana and other fruits. It does not need large spacious cages.
- It lives happily in an ordinary glass bottle of jams and marmalades. It eats yeast that grows on mashed banana.
- Male and female Drosophila show sexual **dimorphismi.e. These are morphologically** distinct from each other.
- **Male** is smaller in size with black rounded abdomen.
- **Female** is larger with pointed abdomen.
- **Male has sex combs on front legs.**
- Drosophila has a generation time of just **two weeks.**
- It lays a large number of eggs which hatch out into fertile offspring.
- Many generations can be raised in a relatively short time.
- Drosophila is perfectly suited for genetic studies.
- It shows fairly large number of distinct contrasting traits.
- Morgan and his colleagues studied pattern of inheritance of **more than 85 traits** of Drosophila.
- Its larvae are excellent material for dissection for chromosome study.
- It has **only eight** chromosomes in four homologous pairs that can be conveniently studied under a microscope.
- Its **salivary gland cells have giant** chromosomes in their nuclei. These giant chromosomes have characteristic banding patterns corresponding to genes.
- The **entire genome of Drosophila has been successfully** sequenced as part of human genome project.
- Morgan raised cultures of Drosophila flies to study different traits, such as **color of the eye.**
- Normal fruit flies, the wild type, have **bright red eyes.**
- One of his coworkers, Calvin Bridges, observed an unusual white eye mutant male fly.

### STEP 1

- Morgan mated this white-eyed male with a wild type red-eyed female.
- All **1237** offspring of this cross had red eyes. Morgan concluded that red eye is a dominant trait.

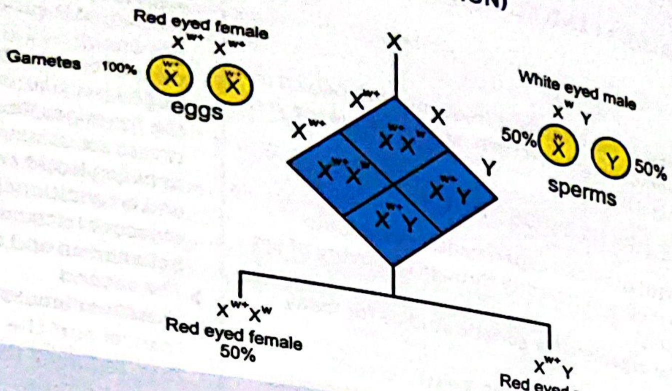
slightly less than the sum of the **b-cn** and **cn-vg** frequencies **(9+9.5-18.5%)** because of the few times that crossover occurs between **b** and **cn** and an additional crossover occurs between **cn** and **vg.**

- The second crossover would "cancel out" the first, reducing the observed b-vg recombination frequency while contributing to the frequency between each of the closer pair of gene.
- The value of **18.5% (18.5 map units)** is closer to the actual distance between the genes, so a geneticist would add the smaller distances in constructing a map.

**BTB**

- The sex chromosomes (X and Y) contain genes which are related to sexual character (traits) of male and female.
- However, besides controlling sexual traits, the sex chromosomes also contain other genes which are not concerned with sexual traits.
- This phenomenon is called **sex linkage.**

First step cross




## STEP 2

- Morgan allowed males and females of $F_1$ generation to mate and produce $F_2$ generation.
- He counted **2459** red-eyed females, **1,011** red-eyed males, and **782** white-eyed males among $F_2$.
- The proportion of **3470** red-eyed to **782** white-eyed flies did not perfectly fit into Mendelian 3:1 ratio.
- The number of recessive phenotype individuals was too small.
- There was another peculiarity in this result. All the white-eyed flies were only males. There was no white eye female in $F_2$ generation.
- The inheritance of eye color somehow seemed to be related to the 'sex' of the offspring. Morgan proposed that:
  i. The gene for eye color is located on X chromosome,
  ii. The alleles for eye color are present only on X chromosome. There is no corresponding allele for this trait on Y chromosome.
- Thus, even a single recessive allele on X chromosome can express itself in males because Y chromosome is empty for that gene.
- Males are hemizygous as they carry just one allele on their only X chromosome.
- Females have two X chromosomes, each carrying an allele of the trait.
- Females can be homozygous or heterozygous.
- Symbol "w" represents the recessive allele for white eye, and "$w^+$" designates its wild type allele for red eye.
- The genotypes of the parents of P1 cross were: $X^{w+}X^{w+}$ for red eye female, and $X^{w}Y$ for the white eye male.
- Morgan's hypothesis explained clearly why all the white eyed flies in $F_2$ generation were only males.

## STEP 3: TEST CROSS

- Morgan wanted to test his hypothesis
- He crossed the P1 white eyed male (XWY) with one of its own daughters, the red eyed heterozygous female from $F_1$ generation.
- This test cross produced **129** red-eyed females, **132** red- eyed males, **88** white-eyed females and 86 white eyed males.
- White-eyed flies were less viable than red-eyed flies.

e.g. gene for blood clotting factor VIII, gene for opsin pigment in eye, gene for hairy pinna, etc.

- An allele that is located only on X-chromosome (i.e. non-homologous portion) is called X-linked.
- The allele that is only located on the (non-homologous portion) of Y chromosome is called Y-linked or holandric traits.

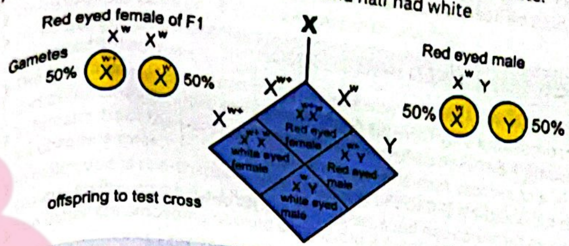
**KPK**

- In **1909**, a white eyed male appeared in a Laboratory bottle.
- Apparently, the variant (white eye mutant) form arose through a **spontaneous mutation** in a gene controlling eye colour.
- Morgan established true breeding traits of white eyed males and females.
- He did a series of Reciprocal crosses.
- Morgan experiments were designed to test prediction derived from his hypothesis that factor for eye color is associated with X chromosomes.



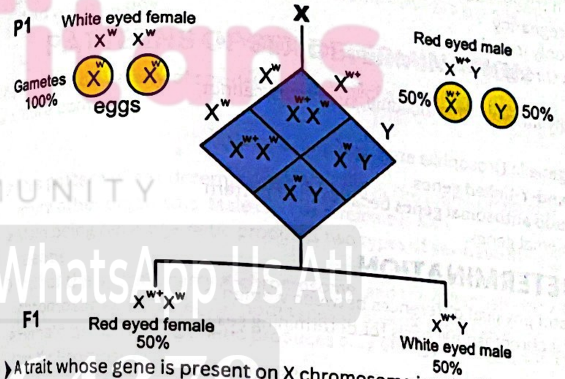


- Half the female offspring in fact had red eyes and half had white.
- Similarly half the males had red eyes and half had white




## STEP-4: RECIPROCAL CROSS AS A CONFIRMATORY TEST

- Appearance of white eyed female provided an opportunity for a further confirmatory test. Morgan mated a white eyed female with a red-eyed male
- All female offspring had red eyes, and all male offspring had white eyes.
- Then these $F_1$ red eyed females and white eyed males were mated to produce $F_2$.
- **Half of the $F_2$ females had red eyes, half had white. Similarly half of the $F_2$ males had red eyes and half had white. This $F_1 \times F_1$ cross was exactly like step-3 test cross.**




- A trait whose gene is present on X chromosome is called **X-linked trait.**
- X-linked traits are commonly referred as sex-linked traits.
- A gene present only on X chromosome, having no counterpart on Y chromosome, is called X - linked gene.

**FTB**

**Mendel's Conclusion**

- A simple explanation of his results, Morgan concluded that the white-eye trait gene resided on the X chromosome.
- Morgan had only to assume that the Y chromosome did not have this gene (it was later shown to carry almost no functional genes).

- Knowing from his previous crosses that white-eye is a recessive trait, the results he obtained could be seen to be a natural consequence of Mendelian segregation.

## SIGNIFICANCE OF SEX-LINKED INHERITANCE

- Sex-linked inheritance follows a very specific pattern.
- As a son inherits his X chromosome only from his mother, and a daughter gets X chromosome from each parent.
- An X-linked trait passes in a crisscross fashion from maternal grandfather (P1) through his daughter ($F_1$) to the grandson ($F_2$).
- It never passes directly from father to son because **a son inherits only the Y chromosome from father**.
- Morgan's discovery of sex-linked inheritance was a great contribution to the understanding of genes and chromosome.
- In **1933**, T. H. Morgan was awarded a Nobel Prize for his contributions to genetics.

## Y LINKED TRAIT AND Y LINKED INHERITANCE

- Y chromosomes are not completely inert. It does carry a few genes which have no counterpart on X chromosome.
- Such genes are called **Y-Linked genes**, and their traits are called **Y-linked traits**.
- e.g. SRY' gene on Y chromosome determines maleness in man.
- It is male sex switch which triggers developmental process towards maleness after **6-week pregnancy**
- Y-linked traits are found only in males.
- These traits directly pass through the Y chromosome from father to son only.
- As females do not normally inherit Y chromosome, such traits cannot pass to them.
- Some genes like bobbed gene in Drosophila are present on X and Y both. These are called **X-and-Y-linked genes**.
- These are also called **Pseudo autosomal genes** because their pattern of inheritance is like autosomal genes.



## SEX DETERMINATION

- Although the anatomical and physical differences between women and men are numerous, the chromosomal basis for determining sex is rather simple.
- A clear picture of the genetic basis of sex determination emerged after the discovery of sex chromosomes.

## GENETIC IDENTIFICATION OF SEX PHENOTYPES

- Most of the animals and plants have a genetic difference in male and female individuals which is reflected in their particular array (arrangement) of chromosomes i.e., karyotype.
- Let us see this difference and identify the male and female individuals in Drosophila and human.

# CHROMOSOMES IN DROSOPHILA

- There are **four pairs** i.e., **8** chromosomes in Drosophila.
- Three pairs of chromosomes are identical in male and female, which are called **autosomes.**
- The fourth pair of chromosomes is different in male and the female and determines genders and are called **sex chromosomes.**
- In females both the sex chromosomes are identical, so these are called **XX chromosomes.**
- In males one is rod-shaped and is like the sex chromosome of the female, so it is also called **X-chromosome.**
- The other chromosome hooked shape, and it is called **Y-chromosome.**

# CHROMOSOMES IN MAN

- In humans there are **23 pairs of chromosomes, 22 pairs** of which are autosomes, while one pair is **sex chromosome.**
- In females it is **XX** and **XY** in males.
- Human females have two copies of the **X chromosome.**
- All eggs cells produced by a woman contain one **X chromosome.**
- In male's half of the sperms contain an **X chromosome** and half contain **Y chromosome.**
- The sex chromosome carried by the sperms therefore determines the gender of the child.
- If a sperm carrying **X chromosome** fertilizes the egg, the child will be a **girl,** but if a sperm carrying a **Y chromosome** fertilizes the egg, the child will be a **boy.**

# PATTERNS OF SEX DETERMINATION

There is a wide variety of sex-determining mechanisms, but three patterns are more common.

## XY-XX TYPE

- This pattern of sex determination is found in Drosophila, man and many other organisms. Male is **XY** and female is **XX.**
- Male being heterogametic produces two types of sex-determining sperms.
- Half of the sperms carry **X-chromosome,** and the other half carry **Y-chromosome**. Chances for both types of sperms are equal.
- Female being homogametic produces only one type of eggs, each with an **X chromosome.**
- Sex of the offspring is determined by the type of sperm. If an **X-carrying sperm** fertilizes the egg, the zygote will be **XX**, and a female offspring is produced.
- If a **Y-carrying sperm** fertilizes the egg, the zygote will be **XY**, and a male offspring will be produced.
- The sex ratio between male and female offspring is **1:1**.
- Sex ratio indicates chances of the sex of the offspring.
- Chances for a son or daughter in human birth are equal.

## XO-XX TYPE

- This pattern of sex determination is found in **grasshopper and**

**Protenor bug.**

- Male is XO because it has only one X chromosome. The other sex chromosome is missing.
- Male is heterogametic because it forms two types of sperms, half of the sperms have X without any sex chromosome.
- A gamete without any sex chromosome is called **nullo gamete.**
- Female is XX, because it has two X chromosomes. It is homogametic, as it forms only one type of eggs. Every egg carries an X chromosome.
- Sex of the offspring depends on the kind of sperm that fertilizes the egg.
- If an X-carrying sperm fertilizes the egg, an XX female offspring is produced.
- If the nullo sperm fertilizes the egg, an XO male offspring is produced.
- Sex ratio between male and female offspring is **1:1**.

## XX–XY OR WZ–ZZ TYPE

- This type of sex-determination pattern is common in birds, butterflies, and moths.
- It is the reverse of XY - XX system.
- Here the female is heterogametic XY, but the male is homogametic XX.
- Female produces two kinds of eggs X and Y in equal proportions.
- All sperms are alike, each carrying an X-chromosome.
- The kind of egg that determines the sex of offspring.
- When an X-carrying egg is fertilized by the sperm, a male offspring is produced, but when a Y-carrying egg is fertilized by the sperm, a female offspring is produced.
- Sex ratio is **1:1**

## COMPARISON OF CHROMOSOMAL DETERMINATION OF SEX BETWEEN DROSOPHILA & HUMANS

- Although both Drosophila and humans follow the same XY - XX sex-determining pattern, yet there is a basic technical difference between the two.
- Presence of "SRY" gene on Y chromosome is essential for triggering the development of maleness in humans.
- Absence of Y chromosome simply leads to the female development path.
- **XO Turner's syndrome** in humans produced through non-disjunction is a sterile female. But in **Drosophila XO** is a **sterile male**.
- Similarly, XXY individual produced through non-disjunctional gametes in **humans** is a **sterile male** called **Klinefelter's syndrome**, but the same XXY set of chromosomes in **Drosophila** produces a **fertile female.**

| Species | XX ( ) | XY( ) | XO( / ) | XXY( / ) |
|---|---|---|---|---|
| Drosophila | ♀ | ♂ | ♂ (Sterile) | ♀ (Fertile) |
| Human | ♀ | ♂ | ♀ (Sterile) | ♂ (Sterile) |

- There is a close genic balance between genes of different chromosomes.
- Drosophila has an X chromosome-autosome balance system.
- Its Y chromosome appears to have very little influence on sex.
- Here actually the X chromosome is female determining and the autosomes are male determining.
- Sex of an individual depends more on the number of X chromosomes relative to the number of sets of autosomes.
- An X: A ratio of 1.00 or **higher produces female**.
- Whereas an **X: A ratio of 0.5** or **lower produces males**

# SEX-LINKAGE IN HUMANS

- Humans have many X-linked traits of which some like haemophilia and colour blindness are recessive while others like hypophosphatemic or vitamin D resistant rickets are dominant.
- **X-linked dominant** is a trait which is determined by an X linked dominant gene, while **X-linked recessive** is a trait that is determined by as X-linked recessive gene.
- Their patterns of inheritance are very different from each other.
- **Experimental mating is not practically possible in humans.**
- **Mode of inheritance of human traits can be traced through pedigrees.**

## X-LINKED RECESSIVE INHERITANCE

- **Characteristics of X-Linked Recessive Inheritance:**
- Females possessing one X-linked recessive mutation are considered carriers and will generally not manifest clinical symptoms of the disorder.
- All males possessing an X-linked recessive mutation will be affected (males have a single X-chromosome and therefore have only one copy of X-linked genes).
- Thus, X linked recessive inheritance is more common in males.
- All offspring of a carrier female have a **50%** chance of inheriting the mutation.
- All female children of an affected father will be carriers (daughters possess their fathers' X-chromosome).
- No male children of an affected father will be affected (sons do not inherit their fathers' X-chromosome).
- Some examples of X-linked Recessive Disorders:
- Haemophilia A and B, Colour Blindness, Diabetes Insipidus and Testicular Feminization.



## X-LINKED DOMINANT INHERITANCE

- **Characteristics of X-Linked Dominant Inheritance:**
- A male or female child of an affected mother has a **50%** (equal) chance of inheriting the mutation and thus being affected with the disorder.
- All female children of an affected father will be affected (daughters possess their fathers' X-chromosome).
- No male children of an affected father will be affected (sons do not inherit their fathers' X-chromosome).
- Some examples of X-Linked Dominant disorders:

**Functions of lipids**

- Alport's syndrome
- Coffin-Lowry syndrome (CLS)
- Idiopathic hypopara-thyrodism
- Vitamin D resistant rickets
- Incontinentia pigmenti

## Y-LINKED INHERITANCE

- In mammals, Y-linkage refers to when a phenotypic trait is determined by an allele (or gene) on the Y chromosome.
- It is also known as **holandric inheritance.**
- The Y-chromosome is small and does not contain many genes, therefore few traits are Y-linked, and Y-linked diseases are rare.
- Because the only humans which have a Y chromosome are males, the genes are simply passed from father to son, with no interchromosomal genetic recombination.
- Chromosome Y deletions are a frequent genetic cause of male infertility.
- Another example in humans of a Y-linked trait was thought to be hairy ears (it may also be sex-limited). However, this has been discredited.
- The examples of Y-linked characters in man are **hypertrichosis** (growth of hair on the rim of pinna), **porcupine man** (straight hair on the body), and **webbing of toes.**
- Recently two more genes have been discovered, **testis determining factor (TDF)** and **minor histocompatibility gene (H-Y).**

## SEX LINKED DISORDERS IN HUMAN

- Humans have several disorders which are caused by the **mutation in sex chromosomes** as drosophila has white eye colour.
- The inheritance patterns of some sex liked disorders in human discussed here



### HAEMOPHILIA

- Haemophilia is a **rare X-linked recessive trait.**
- Haemophiliac's blood fails to clot property after an injury, because it has either a reduction or malfunction or complete absence of blood clotting factors.
- It is a serious hereditary disease because a haemophiliac may bleed to death even from minor cuts.
- Haemophilia is of three types: A, B and C.

| Sr # | Types of Haemophilia | Cause | % | Inheritance |
|---|---|---|---|---|
| 1. | Haemophilia A (Severe Type) | Abnormality of blood clotting factor VIII | 80% (Most Common) | Recessive X-linked |
| 2. | Haemophilia B (Moderate Type) | Disturbance in blood clotting factor IX (Christmas factor) | 20% (2nd Most Common) | Recessive X-linked |
| 3. | Haemophilia C (Mild Type) | Reduction in blood clotting factor XI | Less than 1% | Recessive autosomal |

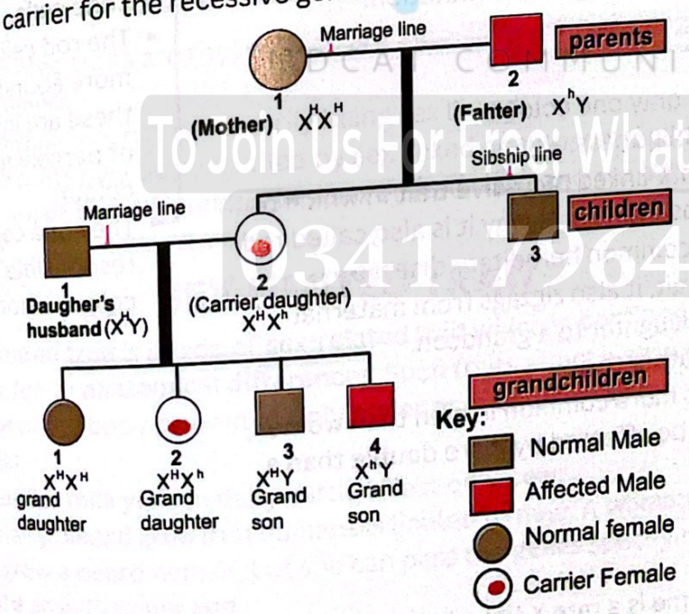
**BTB**

- The haemophilia called **royal disea** because haemophilia gen was passed from Queen Victoria v became Queen England in **1837** ruling families o Russia, Spain ar Germany.
- Queen Victoria gene of haemophilia w caused by **spontaneous mutation.**

- Haemophillia A and B are **X-linked recessive**, but **haemophillia C** is an **autosomal recessive trait.**
- Being X-linked recessives, haemophilia A and B affect men more than women, but haemophilia C affects both sexes equally because it is autosomal.
- **Chances for a man to be affects by haemophillia A and B are double than a woman.**
- A woman can suffer from haemophilia A or B only when she is homozygous for the recessive allele, but a man with just one recessive allele will display the trait.
- Haemophilia A and B **zigzag** from maternal grandfather through a carrier daughter to a grandson
- It never passes direct from father to son.
- Gene for normal **is H** and gene for haemophilia A **is h.**

**PTB**

- Haemophilia A and B are non - allelic recessive sex – linked.
- In generation I of this pedigree a man **(I - 2)** suffering from haemophilia A marries a normal woman **(I - 1).**
- He passes haemophilia genes to his daughter **(II - 2)** through his X chromosome.
- He cannot pass this gene to his son **(II-3)** because the son receives only Y chromosome from him.
- His daughter **(II-2)** also receives another X but with a normal dominant allele from her mother **(I - 1).**
- The daughter looks phenotypically normal, but she is heterozygous and a carrier for the recessive gene.




- When she marries a normal man **(II - 1)** she passes her father's trait to one of her two sons **(HI - 4)** who inherits grandfather's X from her.
- The single recessive allele for haemophilia expresses successfully in the hemizygous son because his Y chromosome does not carry its counterpart.
- The other son **(III-3)** is normal as he inherits grandmother's X with

**HOW DOES BLOOD CLOT?**

- Within seconds of cutting a **blood vessel**, the damaged tissue causes **platelets** to become 'sticky' and clump together around the cut.
- These 'activated' platelets and the damaged tissue release **chemicals**. These **chemicals** then react with other **chemicals** and proteins in the plasma, called **clotting factors.**
- Next to a cut, a complex series of reactions involving these **clotting factors** then happens quickly.
- Each reaction triggers the next reaction.
- This is called a **cascade.**
- The final step of this cascade of chemical reactions is to convert **factor I** (also called **fibrinogen - a soluble protein)** into thin strands of a **solid protein** called **fibrin.**
- The strands of **fibrin** form a **meshwork** and trap **blood cells,** which form into a **solid clot.**
- There are **13 known clotting factors** which are called by

- normal gene. One daughter (III - 1) with both normal X is normal, but the other daughter (III - 2) is carrier like her mother.
- Many X - linked traits in man are also found X - linked in other mammals like mouse, rabbit, dog, sheep, horse, donkey, cattle, kangaroo and chimpanzee.

# GENETICS OF COLOUR BLINDNESS

- Normal trichromatic colour vision is based on three different kinds of cone in the retina, each sensitive to only one of the three primary colours: red, green, or blue.
- Each type of cone cell has specific light-absorbing proteins called **opsins**.
- The genes for red and green opsins are on the X chromosome, while the gene for blue opsin is present on autosome 7 (so equally expressed in male and female).
- **Protanopia** is red blindness, **deuteranopia** is green blindness, while **tritanopia** is blue blindness.
- **Protanomalous** is a defect of vision characterized by a diminished response of the retina to red.
- **Deuteranomalous** exhibits partial loss of green color vision so that an increased intensity of green is required in a mixture of red and green to match a given yellow.
- Mutations in opsin genes cause colour-blindness like dichromacy and monochromacy.

## DICHROMACY

- A dichromate can perceive two primary colours but is unable to perceive the one whose opsin is missing due to mutation.

## MONOCHROMACY

- A monochromate can perceive only one colour.
- Monochromacy is true colour-blindness.
- Blue cone monochromacy is an X-linked recessive trait in which both red and green cone cells are absent. That is why it is also called **red-green colour-blindness**. It is a common hereditary disease.
- Like any sex-linked recessive trait, it also zigzags from maternal grandfather through a carrier daughter to a grandson.
- It never directly passed from father to son.
- This type of colour blindness is more common in men than women, because chances for a male to be affected by it are double than a female.



**BTB**

- Colour Blindness is not a form of blindness at all, but a difficulty in distinguishing certain colors, such as blue, yellow, red and green.
- It is infact a **colour vision deficiency**.
- It is an X-linked recessive inheritance therefore more common in males than females.
- There are two types of photoreceptor cells in the retina of the eye i.e. rod and cone cells.
- The rod cells are more abundant, but these are incapable of perceiving colour.
- The cone cells are responsible for colour vision.

**PTB**

- **Testicular feminization syndrome** is a rare X-linked recessive trait
- Although the persons affected by this trait have a male set of XY chromosomes, yet tfs gene on their X chromosome develops them physically into females.
- They have breast, female genitalia, a blind Vagina but no uterus.
- Degenerated testes are also present in abdomen.
- Such individuals are happily married as females but are sterile.

- It is an **androgen insensitivity syndrome.**
- Male sex hormone testosterone has no effect on them.

FTB

## GENETICS OF MUSCULAR DYSTROPHY

- **Muscular dystrophy**, as the name implies, is characterized by a **wasting away of the muscles.**
- The most common form is **Duchenne muscular dystrophy.**
- It is a **sex-linked recessive disorder.**
- The **symptoms** appear in **early childhood**, when the child begins to have difficulty **standing up** and rises to a standing position in a **characteristic way.**
- By the age of **12**, the patient is **wheelchair-bound.**
- Eventually, the patient becomes severely **wasted**, and **normal breathing** becomes difficult.
- **Death** usually occurs by the age of **20**, so affected males are **rarely fathers.**
- The **recessive allele** remains in the population through passage from **carrier mother to carrier daughter.**
- The **gene** whose **mutation** causes this disorder has been mapped.
- It codes for a **protein called dystrophin**, which is present in normal muscles but **missing in Duchenne patients.**
- The **lack of dystrophin** causes **calcium to leak** into the cell, promoting the action of an **enzyme that dissolves muscle fibres.**



## SEX RELATED TRAITS

- Sex related traits are those which are **associated with maleness or femaleness.**
- These traits are not necessarily being sex linked.
- These traits may be controlled by sex linked or autosomal genes.
- They are of **two different types:** sex limited traits and sex Influenced traits.

## SEX LIMITED TRAIT

A **sex-limited trait** is a type of **sex-related** trait which is **confined to only one sex** due to **anatomical differences**. Such traits affect a **structure** or **function** of the body present in **only males** or in **only females.**

**Example:**

- Genes for **milk yield** in dairy cattle affect only **cows.**
- Similarly, **beard growth** in humans is limited to men. A **woman** does not grow a beard herself, but she can pass the **genes** specifying **heavy beard growth** to her **son.**

## SEX INFLUENCED TRAIT

- **Sex-influenced traits** are also a type of **sex-related traits.**
- These occur in both **males** and **females**, but they are **more common in one sex.**
- **Sex-influenced traits** are controlled by an **allele** that is expressed as dominant in one but **recessive** in the other. This difference in

**BTB**

- Some women can have a **genetic** mutation that makes them **tetrachromatic**, which causes their eyes to have **4 different types of cone cells**, enabling them to see **1000 million different colors** as compared to a **normal person** who can see **100 million.**

- expression is due to hormonal differences between the sexes.
- **Examples:**
  - The amounts of **body hair, muscle mass,** and **male pattern balding** are **sex-influenced traits.**
  - Many more **men** than **women** are bald.
  - It is inherited as an **autosomal dominant** trait in **males** but as an **autosomal recessive trait in females.**
  - A **heterozygous male** is **bald**, but a **heterozygous female** is not.
  - A **woman** can be **bald** only when she is **homozygous recessive.**

**Pattern Baldness in Humans:**

| Genotype | Phenotype in Male | Phenotype in Female |
|---|---|---|
| B1B1 | Bald | Bald |
| B1B2 | Bald | Normal Hairs |

# EVOLUTION

## INTRODUCTION

- Evolution refers to the processes that have **transformed life on earth** from its **earliest forms to the vast diversity** that we observe today.
- Evolutionary change is based mainly on the interactions between populations of organisms and their environments.
- Whenever we say or hear the word evolution, name of **Darwin** comes in our mind immediately.
- In fact, he was the first person who argued from evidence that species were not specially created in their present forms, rather they had evolved from ancestral species.
- He also proposed a mechanism for evolution, which he termed Natural Selection.

**BTB**

- The central idea of biological evolution is that all life on earth shares a **common ancestor.**
- Evolution is defined as "descent with modification," as Darwin proposed that present-day species differ from their ancestral forms.
- Evolution can also be defined more **narrowly as a change in the genetic composition** of a population from generation to generation.
- Evolution is the only scientific explanation for **life's diversity,** accounting for similarities among varied species.

## FOCUS CONCEPT OF EVOLUTION

- The theory of evolution states that species change over time.
- The **primary mechanism** for this change is **natural selection.**
- Evolution rarely follows a straight line from species to species.
- It is more like a tree with many branches. Some branches lead to new branches while other become dead ends.

## CONCEPT OF EVOLUTION VS SPECIAL CREATION

Two schools of thought emerged in the earlier 19th century. **Creationists** believed in the Theory of Special Creation, whereas **evolutionists** believed in the Theory of Natural Selection.

## THEORY OF SPECIAL CREATION

- According to the theory of special creation, all living things came into existence in their present forms especially and specifically created by Nature.
- Among the scientists who believed in divine creation was Carolus Linnaeus **(1707-1778)**.

**FTB**

- Creationists believed that during unlimited period, God created the universe and man as supernatural event at a particular time in past.
- This theory explains that every species was individually created by God in the form in which it exists today and is not capable of undergoing any change.
- They reject any other possible views and rely absolutely on inspiration, meditation and divine revelation.

**KPK**

- **Aristotle (384-322 B.C)**, one of the first great naturalists, categorized all the living things he encountered.
- He believed that organisms fit into an orderly scheme later termed the **Scala Naturae** or
- Ladder of Nature. The ladder stood, so to speak, upon

## CONCEPT OF EVOLUTION

- The idea that organisms might evolve through time, with one type of organism giving rise to another type of organism, is an ancient one, existing from the days of Aristotle.
- Aristotle recognized that organisms ranged from relatively simple to

very complex structures.

- However, the present-day concept of evolution is based on a known history.
- As you know, Carolus Linnaeus in the eighteenth-century classified organisms.
- He grouped similar species in the same genus and similar genera in one family.
- But as a natural theologian, he believed that species were permanent creations. A century later, the taxonomic system of Linnaeus became a focal point in Darwin's arguments for evolution.

| Scientist Name | Life Span | Achievements |
|---|---|---|
| Linnaeus | 1707–1778 | Introduced binomial nomenclature for naming species; sought and found order in the diversity of life. |
| Lamarck | 1744–1829 | Published his theory of evolution. |
| Malthus | 1766–1834 | Published Essay on the Principle of Population. |
| Cuvier | 1769–1832 | Contributed to palaeontology and explained Earth's history through catastrophism. |
| Lyell | 1797–1875 | Published Principles of Geology. |
| Darwin | 1809–1882 | 1. Voyage of Beagle. 2. Began his notebooks on the origin of species. 3. Wrote his essay on the origin of species. |
| Mendel | 1822–1884 | Published papers on inheritance. |
| Wallace | 1823–1913 | Sent his theory on evolution to Darwin. |

**FTB**

- The supporters of evolution are known as evolutionists.
- They have believed that the universe and man did not always exist in their present form, neither are they the product of a sudden creative act but rather the **result of innumerable changes** from the lower to the higher, each step-in advance being an evolution from a pre-existing situation.
- Modern biologists believe that the **Earth is over 5 billion years old**. Then about **3.5 billion years** ago, life began.
- According to evolutionists, life on Earth had emerged as a unicellular prokaryote then with the passage of time variation have been accumulated new species came into existence.
- The current biodiversity including man is the descendent of the earliest unicellular prokaryote that might had originated spontaneously.



## EVOLUTION FROM PROKARYOTES TO EUKARYOTES

### VENT HYPOTHESIS

- One of the speculations trying to explain the origin of life is that it may have begun deep in the oceans, in **underwater hot springs** called hydrothermal vents.
- These vents could have supplied the energy and raw materials for the origin and survival of early life forms.
- A group of bacteria, called **archaeobacteria** that tolerate

non-living matter climbed rung by rung from fungi and mosses to higher plants through primitive animals such as mollusks and insects and was finally terminated in human beings.

- The Scala Naturae was viewed as permanent, with each organism's place ordained by God during creation.

**BTB**

- Special creation is supported by most of the world's major religions and civilizations.
- This concept is based on the references of Holy books.
- According to their interpretations that **Allah has created everything in the universe in six days and human was created at sixth day.**
- Faith accepts concepts without scientific evidence, so there is no conflict between scientific and theological creation accounts, since they are mutually exclusive **realms of thoughts**.
- In most cases the **scientific truth** to the scientists is **tentative**, but

- Temperatures up to **120°C** and seem to have undergone less evolutionary change than any other living species supports this vent hypothesis.
- According to evolutionists, they are the **first living being** on Earth.
- The nutrients produced in the primitive environment would have limited early life.
- If life were to continue, another source of nutrients was needed.
- Photosynthesis probably freed living organisms from a dwindling supply of nutrients.

## CONVERSION OF REDUCING ATMOSPHERE TO OXIDIZING ATMOSPHER

- The **first photosynthetic organisms** probably used hydrogen sulphide as a source of hydrogen for reducing carbon dioxide to sugars.
- These prokaryotes still use **hydrogen sulphide ($H_2S$)** as **source of hydrogen** for carbohydrate and produce sulphur (S) as by-product.
- Later, when **cyanobacteria** evolved, these started using **$H_2O$ as source of hydrogen** in synthesizing carbohydrates and liberated $O_2$ as a by-product which began to accumulate in the atmosphere.
- Earth and its atmosphere slowly began to change.
- **Ozone** in the upper atmosphere began to **filter ultraviolet radiation**
- from the sun, the reducing atmosphere slowly became an oxidizing atmosphere, and at least some living organisms began to utilize oxygen.
- About **420 million years ago**, enough protective ozone had built up to make life on land possible.
- Ironically, the change from a reducing atmosphere to an oxidizing atmosphere also meant that life could **no longer arise abiotically**.
- The **first cells** were most likely very **simple prokaryotic forms** that may have arisen more than **3.5 billion years ago**.
- **Eukaryotes** are thought to have first appeared about **1.5 billion years** ago.

**FTB**

- Evolutionists hypothesized that about more than **3.5 billion years ago** the first thing being originated on earth in hot water springs (called hydrothermal vents) through **spontaneous reaction through different organic and inorganic molecules**.
- The evolutionists concluded that the early atmosphere of earth was reduced (without oxygen), hot and ozone less, therefore, frequent exposure of UV radiations was there.
- The early prokaryotes were **absorptive heterotrophs**, and then **chemosynthetic autotrophs** came into existence.

## THEORIES ABOUT EVOLUTION OF EUKARYOTES

### 1. ENDOSYMBIOSIS THEORY

**(SYMBIOSIS MEANS LIVING TOGETHER AND ENDO MEANS WITHIN)**

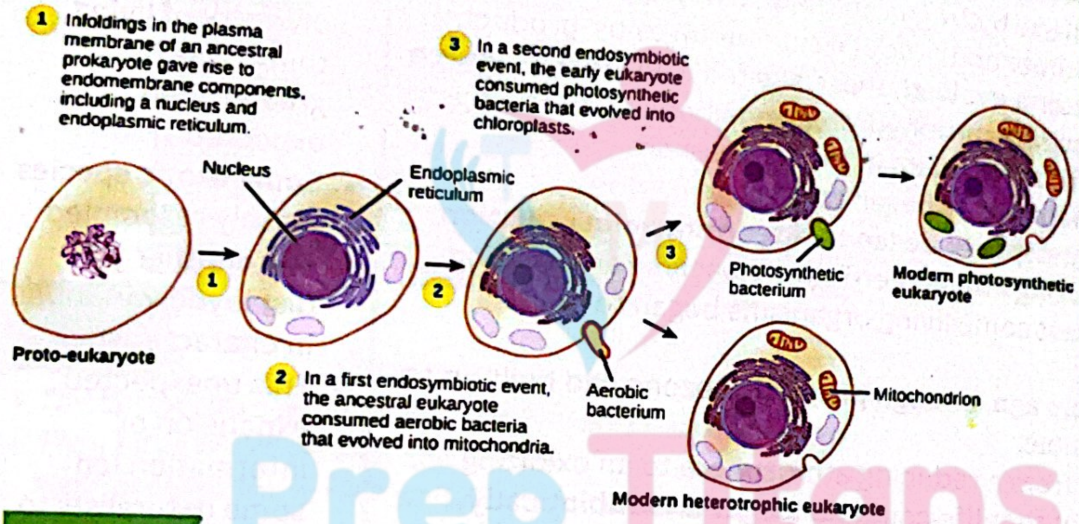
**theological truth** to the believer is **absolute**.

**KPK**

- The idea of creationism reigned unchallenged fo **nearly 2000 years**.
- As European naturalists explored newly discovered lands in Africa, Asia, and America, they found that the diversity of living things was far greater than expected.
- Some exotic species closely resembled one another yet displayed variations in characteristics.
- This unexpected expansion of information led some naturalists to consider that species might change and that similar species could have developed from a common ancestor.
- Later, the discoveries of fossils added credibility to this view.
- Fossil remains showed a remarkable progression in form.
- **Fossils in the oldest rock layers** were very different from modern forms, with a gradual advancement

- The eukaryotic cell might have evolved when a **large anaerobic** (living without oxygen) **amoeboid prokaryote** ingested small aerobic (living with oxygen) bacteria and stabilized them instead of digesting them.
- This idea is known as the endosymbiont hypothesis and was **first proposed by Lynn Margulis.**
- According to this hypothesis, the aerobic bacteria developed into **mitochondria**, which are the sites of aerobic respiration and most energy conversion in eukaryotic cells.
- The possession of these mitochondria like endosymbionts brought the advantage of aerobic respiration to the host.
- **Flagella (whip like structures)** may have arisen through the ingestion of prokaryotes similar to spiral-shaped bacteria called **spirochetes.**
- Ingestion of prokaryotes that resembled present-day **cyanobacteria** could have led to the endosymbiotic **development of chloroplasts** in plants.

The ENDOSYMBIOTIC THEORY






**FTB**

- As per fossil record eukaryotes appeared **1.9-2.1 Billion years**
- Mitochondria and chloroplasts are similar in size to bacteria, have their own DNA, have ribosomes similar to that of bacteria, and produce a limited number of their own enzymes and proteins.
- To explain these observations, it is suggested that the endosymbionts must have transferred, over time, some of their genes to the host nucleus and thus relinquished their independence for the sake of symbiotic relationship.
- Mitochondria and Chloroplasts are said to be **organelles of endosymbiont origin.**

## 2. MEMBRANE INVAGINATION THEORY

- Another hypothesis for the evolution of eukaryotic cells proposes that the **prokaryotic cell membrane invaginated** (folded inward) to enclose copies of its genetic material.
- This invagination resulted in the formation of several double membrane bound entities (organelles) in a single cell.
- These entities could then have evolved into the eukaryotic mitochondrion, nucleus, chloroplast etc.
- Whatever the exact mechanism for the evolution of the eukaryotic

toward modern resemblance in younger rocks—as a Scala Naturae stretched back in time.

**BTB**

- According to **big bang theory the life** began on earth about **3.5 billion years** ago.
- Eukaryotes developed from prokaryotes about **1.9-2.1 Billion years** ago.
- The concept of evolution did not begin with Darwin and the publication of his book "Origin of Species".
- Evolutionary concepts were present at the time of Aristotle about **(384-322BC).**

**BTB**

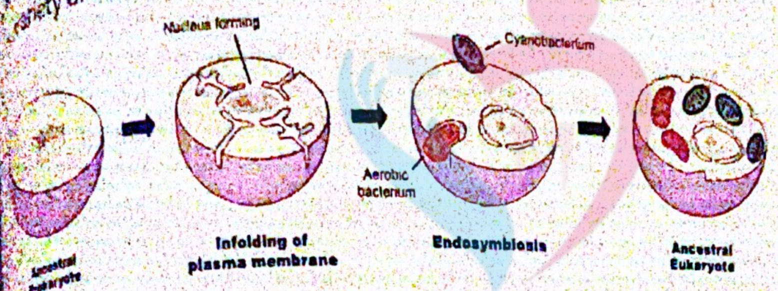
- The first sea hydrothermal vent was discovered in **1977** in the Pacific Ocean.

**INFORMATION**

- Monkeys are different from ape Monkeys have tails and narrow chest. Apes are tailless and have broad chests.
- You might think that you are special but believe it or not you share **about 50%** of

mitochondrion, nucleus, chloroplast etc.

- Whatever the exact mechanism for the evolution of the eukaryotic cell might be, the formation of the eukaryotic cell led to a dramatic increase in the complexity and diversity of life-forms on the earth.
- At first, these newly formed eukaryotic cells existed only by themselves.
- Later, however, some probably evolved into multicellular organisms in which various cells became specialized into tissues, which, in turn, formed organs for many different functions.
- These multicellular forms then adapted themselves to life in a great variety of environments.




# LAMARCKISM

## INTRODUCTION

- Lamarck was a French naturalist, soldier and biologist.
- Lamarck was an early proponent of the idea that evolution (descent with modification) occurred and proceeded in accordance with the natural laws.
- Lamarck is regarded as a premier authority of plants and invertebrate zoology and well known toponymist (Expert of study of places names).
- He is remembered, at least as a taxonomist of considerable stature. In **1809**, he published a book **Philosophie Zoologique** (Zoological Philosophy).
- He was first a soldier, then botanist and finally a professor of zoology in Paris.
- Lamarkism is the **earliest theory of organic evolution.**

## MAIN POINTS OF LAMARCKISM

- He pictured evolution as a **(LADDER OF LIFE)** from the simplest to the most complex ones. Man was the top rung of this ladder.
- Lamarck did little in the way of explaining the origin of this ladder. However, he did offer an explanation or the origin of adaptations to the environment.
- According to Lamarck through several generations these acquired characters are continuously inherited and accumulated.
- Gradually a group of organisms would be produced which would be better able to cope with environment.
- Lamarck's explanation of evolution revolved around **two basic assumptions.**

### 1. USE AND DISUSE OF ORGANS

your DNA with a banana and approximately 31% of your genes with yeast, which is a single celled organism.

**ENDOSYMBIOSIS**

- Research conducted by **Lynn Margulis at the University of Massachusetts** supports the hypothesis that two separate mutually beneficial invasions of a prokaryote cell produced the modern-day mitochondria and chloroplast as eukaryotic organelles.

**KPK**

- In this model (endosymbiosis), ancestral mitochondria were small heterotrophs capable of using oxygen to perform cellular respiration and thereby create useful energy.
- They become part of a large cell either by direct invasion as an internal parasite or as an indigestible food source.
- Later a second invasion brought ancestral chloroplasts, which are thought to be small

- Lamarck argued that those parts of the body used extensively to cope with the environment **become larger and stronger**, while those that are not used are **deteriorated, diminished** and ultimately **disappeared** in the successive generations.
- Among the examples Lamarck cited were the **blacksmith** developing a bigger bicep in the arm that works the hammer and **giraffe stretching its neck** to new lengths in pursuit of leaves to eat and the **snakes** which are living in **small holes** and **crevices** have lost their legs.

## 2. INHERITANCE OF ACQUIRED CHARACTERISTICS

- The second idea Lamarck adopted, was called the inheritance of acquired characteristics.
- In this concept of heredity, the modifications an organism acquires during its lifetime can be passed along to its offspring.
- Such characteristics are called acquired characteristics that often emerged **by the use or disuse of organs**.
- According to Lamarck through several generations these acquired characters are continuously **inherited and accumulated**.
- Gradually, a group of organisms would be produced which would be better able to cope with the environment. Evolution in other words would occur.
- **E.g. the long neck of the giraffe.**
- Lamarck reasoned, evolved gradually as the cumulative product of a great many generations of ancestors stretching higher and higher.
- However, now we know that acquired characteristics cannot be inherited.

## EVOLUTION OF GIRAFFE

- According to Lamarck, the ancestors of giraffe looked like horses with small neck and forelimbs.
- Each giraffe, during its lifetime, would try to reach the leaves at the top of trees.
- Each animal would constantly stretch its neck in order to attain this goal.
- As these individuals reproduced, the results of stretching (an acquires characteristic) would be passed on to future generation.
- Each offspring would be born with a slightly longer neck than those of its parents. Thus, long necked giraffes gradually evolved.

## DRAWBACKS OF LAMARCKISM

- Lamarckism is wrong in terms of principles of genetics.
- The anatomical, biochemical and behavioural characteristics that an individual organism displays as it develops trough life is known as its phenotype.
- However, phenotype is based on **two key factors:**
- The **fixed genetic potential of the organism** (or its genotype; this refers to the specific qualities of its genetic material, or DNA)
- The **environmental conditions** which an organism experiences as it grows.
- The first point of Lamarckism i.e. use, and disuse of organs may be

photosynthetic cyanobacteria.

- Mitochondria and chloroplasts have their own genes, circular DNA and RNA, and reproduced by binary fission independent of the host's cell cycle.
- They, therefore, appear to be more similar to prokaryotes than eukaryotes.

**KPK**

- Two proposed pathways describe the invasion of prokaryote cells by two smaller prokaryote cells.
- They subsequently became successfully included as part of a now much larger cell with additional structures and capable of additional functions.
- The process involved in the evolution of eukaryotes are Endosymbiosis and Membrane infolding.

**KPK Membrane Infolding**

- The invasions of the host prokaryotes cell probably were successful because the host cell

acceptable but the characteristics which are acquired during the lifetime have no genetic bases and therefore cannot be inherited to the next generation.

- The scientists of that time were unaware of mechanism of inheritance produced by Mendel in **1865**.

PTB

- Lamarck published his theory of evolution in **1809**, the year Darwin was born.
- Lamarck was in-charge of invertebrate collection at the Natural History Museum in Paris.
- He presented a mechanism to explain how specific adaptations evolve.

BTB

## EXTINCTION OF LIMBS IN SNAKES

- The snakes are believed to have evolved from lizard-like ancestors that had two pairs of limbs.
- Due to disuse of the limbs, the limbs got weaker and shorter and eventually disappeared.

## FLIGHTLESS BIRDS

- It is believed that the ancestors of birds such as Ostrich were able to fly.
- Due to some environmental changes, they had a lot of food and were well protected.
- They did not use wings and as a result the wings became vestigial.

## DRAWBACKS OF LAMARCKISM

- There is no experimental proof of his theory.
- New organs are not formed in organisms by requirement.
- It is not necessary that the acquired character transmits into new generation.
- Moreover, a German biologist **August Weisman**, in **1880s** disproved the Lamarck's theory of inheritance by giving **experimental proof.**
- He removed tails of 68 mice, repeatedly for many generations, and reported that no mice were born without a tail or even with shorter tail. This rejects the theory of inheritance of acquired characters.

## DARWINISM

- Charles Darwin was born on **February 12, 1809**, in Shrewsbury,
- Western England in a wealthy family and **died** at "Down House" in Kent on **April 19, 1882**.
- He is known as **father of evolution**.
- His father was a prominent physician.
- He joined Cambridge University to study theology, even so attended many lectures in biology and geology.
- He was only **22 in 1831** when he accepted the position of naturalist

membrane infolded to surround both invading prokaryotic cells and there by transport them into the cell.

- The membrane did not dissolve but remained intact, and there by created a second membrane around the promitochondria and prochloroplast.
- It is also known that in modern day eukaryotes the inner membrane of both mitochondria and chloroplast contains structures more similar to prokaryotes than eukaryotes. Whereas the outer membrane retains eukaryote characteristics.
- It is also suggested that continued membrane infoldings created the endomembrane system.
- It can be said that possibly the first eukaryotic cell type was miraculously born from prokaryotic, symbiotic, multicellular interactions.

KPK

**George Cuvier (1769-1832)**

abroad on the **HMS Beagle in British Naval ship** around the world. His major mission was to expand the navy knowledge of natural resources e.g. water and food in foreign lands.

- As a naturalist, it was his job to observe and collect the specimens of plants, animals, rocks and fossils wherever the expedition went ashore.
- During this long journey Darwin made observations.

## DARWIN'S OBSERVATIONS DURING HIS VOYAGE

- The Beagle left **Plymouth, England** and cruised slowly along the **east and west coasts of South America.**
- He collected and catalogued thousands of plant (**flora**) and animal (**fauna**) specimens and kept notes of his Observations.
- The Beagle spent almost two months at the Galapagos (means tortoise) Islands.
- The islands are 965 kilometres west of Ecuador. Here Darwin made observations that were important in development of his ideas about evolution.

## OBSEREVATIONS ABOUT SOUTH AMERICAN MAINLAND

- He noticed that flora and fauna of different region of the continent had a definite South American stamp, very distinct from the life form of Europe.
- Further the South American fossils that Darwin found though clearly different from modem species were distinctly South American in their resemblance to the living plants and animals of the continent.

## OBSERVATIONS ABOUT GALAPAGAGOS ISLANDS

- Darwin compared Galapagos animals and plants with those of the South American mainland, noting remarkable similarities and distinct differences.
- He was struck by why Galapagos organisms resembled South American species more than those from other regions.
- The common birds were group of finches.
- Closely related species had beaks of very different sizes and shapes, adapted for feeding on completely different kinds of food.
- Darwin collected **14 types** of finches (mentioned **13** in PTB) on the Galapagos which are although quite similar but seemed to be different species.
- He noted the main differences amongst the finches on each island which were their **beak shape**.
- Finches on each island had beak shapes that were applicable for the type of food that was available on the island.
- Some were unique to individual Islands, while other species were distributed on two or more islands that were close together.
- Darwin pondered these observations and tried to develop a satisfactory explanation for the distribution of species among the islands adaptations as closely related processes.
- After returning to **Great Britain in 1836**, Darwin **perceived the origin of new species and adaptations as closely related processes.**
- A new species would arise from an ancestral form by the **gradual**

- Proposed the theory of catastrophism.
- Cuvier hypothesized that a vast supply of species was created in the beginning. Successive catastrophes produced layers of rock and destroyed many species, fossilizing some of their remains in the process.
- The reduced flora and fauna of the modern world are the species that survived the catastrophes.

**Louis Agassiz (1807-1873)**

- He proposed that there was a new creation after each catastrophe and that modern species result from the most recent creation.

**Hutton & Lyell (Geologists)**

- **James Hutton (1726- 1797)** and **Charles Lyell (1797-1875)** contemplated the forces of wind, water, earthquake and volcanism as agents for creating layered patterns.
- These layers of rocks are evidence of ordinary natural processes, occurring repeatedly over a long period of time.

accumulation of **adaptations** to different environment, separated from original habitat by **geographical barriers**, over many generations, the two populations could become dissimilar enough to be designated as separate species.

- This is apparently what happened to the Galapagos finches.

PTB

- A particularly **puzzling case of geographical distribution** was the **fauna of the Galapagos islands.**
- Most of the animal species on the Galapagos live nowhere else in the world, although they resemble species living on the South American mainland.
- It was as though the islands were colonized by plants and animals that strayed from the South American mainland and then diversified on the different islands.

BTB

- Darwin also observed **giant tortoises** in Galapagos Islands.
- The Galapagos Islands were named for their giant tortoises.
- Darwin noticed that tortoises on one island had **saddle-shaped shells**, while those on another island had **dome shaped shell**.
- This observation made Darwin to think about origin of species.
- The **size of Galapagos tortoise** is about **4 feet**, weight **475 pounds**, average life span is **100 years**, and it feeds on plants.
- In South America, Darwin found fossils that resembled modern animals.

However, they had differences is size and adaptations. It made him realize that living things had ancestors and that species change over time.

## DEVELOPMENT OF THEORY OF EVOLUTION

- Darwin began formulating his theory of natural selection in the late **1830s**, but he went on working quietly on it for many years.
- He wanted to amass a wealth of evidence before publicly presenting his idea.
- In **1842**, Darwin wrote for himself a brief **35-page** sketch of his theory.
- Two years later he enlarged this into an essay of **230 pages**, which he showed to his friends, but did not publish it.
- For the next fifteen years, Darwin continued to collect facts to support his ideas.
- The bases for the development of Darwin's theory of evolution were not only observations about unique distribution of organisms in different regions of the world but he was also inspired by the work of many other scientists of that time.
- Therefore, the ideas of these scientists also contributed in the early development of Darwinism.

### CONTRIBUTION OF CHARLES LYELL AND JAMES HUTTON

- In the early **1830s**, **Charles Lyell** an **English geologist** published a book

This concept is called **uniformitarianism**.

- If slow natural processes alone are enough to produce layers of rock thousands of feet thick then earth must be old indeed, many millions of years old.
- Hutton and Lyell in fact concluded that earth was a eternal: **"No vestige of a beginning, no prospect of an end"**.
- Thus, Hutton and Lyell provided the time for evolution but there was still no convincing mechanism.

### Lamarck (1744-1829)

- He was the first to propose a mechanism for evolution.
- He hypothesized that organisms evolved through the inheritance of acquired characteristics.
- Lamarck proposed that all organisms possess an innate drive for perfection and urge to climb the ladder of nature.
- By the mid **1800** some biologists were beginning to realize that the fossil record and the similarities between fossil

Principle of geology: Darwin took his book on the voyage.

- The book presented arguments to support a theory of geological change proposed by James Hutton called **theory of uniformitarianism.**
- Lyell pointed out the mountains, valleys, deserts, rivers, lakes and coastlines could have come through the action of existing forces and natural conditions.
- Lyell argued that gradual geological processes have gradually shaped Earth's surface.
- A river slowly carves a valley, Mountains are worn down to hills and finally plains the slow pace of these geological processes, main occurs today, indicated that Earth had to the much older than generally.

## CONTRIBUTION OF THOMAS R.MALTHUS

- Darwin returned to England In**1836**. Soon afterwards, he read a work written by the **English political economist** Thomas R. Malthus (**1766-1834**),
- An Essay on the Principle of Population, Malthus noted that **human populations** have the capacity to **increase exponentially (1–2–4–8–16)** and **food supply** has the capacity to **increase arithmetically (1–2–3–4–5–6)** such a relation could result only in a struggle for food and hence for existence itself.
- When populations become too large, famine and disease break out.
- In the end, this keeps populations in check by killing off the weakest members.

## CONTRIBUTION OF ALFRED RUSSELL WALLACE

- In **1858** Darwin received a letter from a fellow naturalist, Alfred R. Wallace (**1823-1913**), who was travelling at that time in Malays.
- Wallace enclosed an essay that he had written, and he asked Darwin to read it and then forward it to Lyell.
- In the essay, Darwin found, almost in his own terms the theory of the origin of species by means of natural selection.
- Darwin almost yielded to Wallace the honour of being the first man to announce the theory.
- However, his friends (Charles Lyell and Dalton Hooker) arranged to present the two papers under joint authorship using a single title, On the Tendency of Species to Form Varieties, and on the Perpetuation of Selection.
- The papers were presented to the Linnaean Society in London on **July1, 1858**.

## WHY WAS THE THEORY ATTRIBUTED TO DARWIN?

- Wallace was the man who motivated Darwin to publish his book The **Origin of Species of Natural Selection**.
- It appeared in November of **1859**. Only a passing reference to man's place in evolution was mentioned in The Origin of Species.
- Twelve years later, Darwin's **Descent of Man** was published.
- This was about the evolution of man, Darwin was much more willing to explore the implications of natural selection particularly in relation to humans, than Wallace was.

forms and modern species could be best explained if present day species had evolved from pre-existing forms.

- The question remains. But how? **In 1858 Charles Darwin and Alfred Russell Wallace** independently provided convincing evidence that the driving force behind evolutionary change was natural selection.

**KPK**

**LAMARCKISM**

- An acquired character may be defined as a structural change in the body of an organism involving a deviation from normal, induced in the lifetime of an individual due to certain changes in the environment or in function i.e. use or disuse of an organ.
- The ancestors of giraffe were forced to live in conditions where there was not enough grass to eat, so they started browsing upon the foliage trees and this effort resulted in elongation of their forelimbs and neck.
- This increase was

- In addition, Wallace was a champion of rather radical social causes and embraced spiritualism - all elements that resulted in the down-play of his role in the discovery of natural selection.

PTB

- By the early **1840s**, Darwin had worked out the major features of his theory of natural selection as the mechanism of evolution.
- In **1844**, Darwin wrote a long essay on the origin of species and natural selection.
- But before it could be published Alfred Wallace, a young naturalist working in the East Indies developed a theory of natural selection essentially identical to Darwin's.
- Wallace's paper, along with extracts from Darwin's unpublished **1844** essay, were presented to the Linnaean Society of London on **July 1, 1858**.
- Darwin quickly finished The Origin of Species by means of natural selection and published it the next year **1859**.
- He started his work in **1836** after returning from **5 years** trip to HMS Beagle.

BTB

- **Hutton** was Scottish geologist, chemist and naturalist.
- He has given the concept of uniformitarianism, which explains the features of the earth's crust by means of natural processes over geological time.

## WHY WAS THE THEORY ATTRIBUTED TO DARWIN?

- Although Wallace developed basically same theory of evolution as described by Darwin.
- Moreover, **Hutton was the first person to propose a mechanism of natural selection** to account for evolutionary change over time.
- Alfred Russell Wallace also motivated Darwin to publish his book about the origin of species by means of natural selection.
- However, Darwin came up with great supporting evidence from a wide variety of scientific disciplines, including palaeontology, geology, vestigial organ, biogeography and comparative anatomy.
- Darwin spent more than **30 years** studying and observing nature before concluding his ideas. Therefore, this theory was attributed to Darwin.
- At the time of Darwin's death in **1882** his book had been published.
- The origin of species has been translated into **29 languages** including, Turkish, Hindi etc.

## DARWIN'S THEORY OF NATURAL SELECTION

- In his book **The Origin of Species** Darwin developed two main points:
- Descent with modification
- Natural selection and adaptation

passed on from generation to generation.

- The loss of limbs in snakes is the result of crawling and concealing habits. The snakes e.g. pythons were provided with limbs but when mammals, e.g. weasel arose, these snakes began to live in burrows to conceal themselves.
- The result was a gradual reduction and eventually loss of limbs, which were not needed in the new habitat.
- Bodily modifications, whether brought through use or disuse or directly by environment cannot lead to the formation of new species unless they are inherited.

KPK

### DARWINISM

- After graduation from Cambridge, Darwin was appointed as a **naturalist by Professor Henslow,** on the ship Beagle.
- Darwin started the voyage, believing in the fixity of species or theory of special creation.
- Darwin was impressed by the peculiar geographical

### 1.DESCENT WITH MODIFICATION

- Descent with modification means **passing on the traits** from parent organism to their offsprings.
- Darwin believed in **perceived unity in life**, with all organisms related through descent from some common ancestor that lived in the remote past.
- In the Darwinian view, the **history of life is like a tree**, with multiple branching and re branching from a common trunk all the way to the tips of the living twigs, symbolic of the current diversity of organisms.
- At each fork of the evolutionary tree is an ancestor common to all lines of evolution branching from that fork

## 2. NATURAL SELECTION AND ADAPTATION

- Natural selection refers to the differential reproductive capacities among the individuals of a population which indicates that some individuals of a population are capable to reproduce while others are not.
- Darwin's mechanism of evolution by natural selection consists of **four observations** about natural world.

### 1.OVERPRODUCTION

- Each species has the Capacity produce more offspring than will survive to maturity Through reproduction, natural populations may exponentially increase in number over time.
- If all offsprings of any species remained alive and reproduce, they will soon over crowd the earth and could destroy all other species.
- **For example**, if each breeding pair of elephants produces six offspring during its **90-year** life span, in **750 years** a single pair of elephants will give rise to a population of **19 million**. Yet elephants have not overrun the planet.



### 2. STRUGGLE FOR EXISTENCE

- Over production lends to the **competition** among the individuals of a population for the limited resources food, water light-growing space: Because there are more individual than the environment can support, not all will survive to reproductive age.
- Other limits on population growth include predators and disease-causing organisms.
- There is always active competition and a three-fold struggle to ensure living, to obtain the maximum amount of food and better place.
- The struggle for existence aims at self-preservation and self-perpetuation.
- The struggle for existence may be:
- **Intra Specific:** Competition among the organisms of same species.
- **Inter Specific:** Competition among the organisms of different species living together. **E.g. Prey or Predation competition**
- **Environmental Struggle or Extra Specific:** Struggle against various environmental conditions.

distribution and distinctive interrelationship among species.

**BTR**

**DESCENT WITH MODIFICATION**

- According to Charles Darwin, all species descended from only a few life forms that had been modified over time.
- This descent with modification as he called it, forms the **backbone of his theory of evolution.**

**KPK**

**Salient features of Darwin-Wallace theory are:**

1. Overproduction.
2. Struggle for existence.
3. Variation.
4. Natural selection or survival of the fittest.
5. Speciation or origin of new species.

**5. SPECIATION OR ORIGIN OF SPECIES**

- The selected or the surviving individuals transmit their useful or successful variation to the succeeding generations.
- These resulting generations may produce descendants, which are quite different

## 3. VARIATIONS

- The individuals in a population exhibit variation in their traits.
- They show great variation of form, size, colour, habit and physiology among themselves.
- No two individuals are alike. Not even identical twins (monozygote).
- According to Darwin Variation necessary for evolution by natural selection must be heritable and are of two types.
- **Harmful Variations and Useful Variations**
- Some of these traits (variations) improve the chances of an individual's survival and reproductive success, whereas other traits do not.

## 4. SURVIVAL OF THE FITTEST

- Those individuals that possess the most favourable combination of characteristics are most likely to survive and reproduce, passing their heritable traits to the next generation.
- **For example**, if there is sudden flood only those organisms that can swim or respire in water, have a better chance to survive and other will die more on the flying animals have a better chance of survival.
- This is called natural selection read as the survival of the fittest.
- The fittest individuals are those that reproduce most successfully in the environment.
- The processes of natural selection thus cause an **increase of favourable alleles** and a **decrease of unfavourable alleles** within the population.
- Over succeeding generations, individual members become better adapted to local conditions, thus, leading to the **evolution of new species**.



**PTB**

- Darwin suggested that populations of individual species become better adapted to their local environments through natural selection. Darwin's theory of natural selection was based on the following observations:
- **Production of more individuals** than the environment can support leads to a struggle for existence among individuals of a population, with only a fraction of offspring surviving each generation.
- **Survival in the struggle for existence** is not random but depends in part on the hereditary constitution of the surviving individuals. Those individuals whose inherited characteristics it them best to their environment are likely to leave more offspring than the less fit individuals.
- This **unequal ability of individuals to survive and reproduce** will lead to a gradual change in a population, with favourable characteristics accumulating over the generations thus leading to the evolution of a new species.

## NEO- DARWINISM

from their ancestors, different enough to be declared as a separate species.

- This is the formation of new species or descent with modification or evolution.
- The phrase "survival of the fittest" associated with Darwin was coined by biologist Herbert Spencer after reading Darwin's work.

**BTB**

- Neo-Darwinism introduced the connection between two important discoveries: the unit of evolution (gene) with the mechanism of evolution (natural selection).

**KPK**

### EVIDENCES OF EVOLUTION

- Giraffes, Elephants and several mollusks show a gradual evolution of body form over time suggesting evolution of species.
- **Archeopteryx**, the fossil bird, discovered from rocks in East Germany.
- This bird possessed

- The Origin of Species convinced most biologists that species are products of evolution.
- An important turning point for evolutionary theory was **the birth of population genetics**, which emphasizes the extensive genetic variation within populations and recognizes the importance of quantitative characters.
- With progress in population genetics in the **1930s, Mendelism and Darwinism were reconciled**, and the genetic basis of variation and natural selection was worked out.
- Thus, a comprehensive theory of evolution that became known as the modern evolutionary synthesis or Neo-Darwinism was developed in the **early 1940s**.
- It is called a synthesis because it integrated discoveries and idea from many different fields, including palaeontology, taxonomy, biogeography, of course, population genetics.

**KPK**

- Since natural selection was proposed, advances in genetics, biochemistry, ecology and palaeontology have enable scientists to identify mutation, genetic drift and gene flow as other natural forces of evolutionary change.
- The pioneering work of **Cheverikov, Mayr, Simpson** and many other led to what become known as the modern synthesis.
- The modern theory accepts five major causes of evolution.

## 1. GENE AND CHROMOSOMAL MUTATION

- As you know, that both gene and chromosomal mutation can bring about **variations**. These variations can lead to evolution.

## 2. GENETIC RECOMBINATION

- **Reshuffling of genes** occurs during sexual reproduction.
- Meiosis causes random assortment of genes during synapsis and rearrangement of paternal and maternal chromosomes in both kinds of gametes.
- Such reassortment of genes is one of the bases for the appearance of new genetic recombination's in the organisms.
- Crossing over of genes during meiosis also adds to the variations.
- Thus, new combination of characteristics in the organism adds to genetic variability.

## 3. NATURAL SELECTION

- Natural selection uses the **variations and mutations** as the **raw materials** for better survivors.
- Thus natural selection due to environment always exerts a selective influence and Molds the species to fit in its changed environment.

both reptilian as well as avian characters.

- Birds are glorified reptiles as they evolved from them.
- A progression of fossils can be traced back over **60 million years** to the **"dawn horse"** called **Eohippus**.
- This small ancestor had **four toes in its front feet** and three in its hind feet.
- The evolutionary pattern that leads to the modern horse included a reduction in the number of toes, the development of more complex teeth, and an increase in size.
- All species become extinct except the ancestral line that ended with Equus.

**BTB**

- The study of comparative anatomy predates the modern study of evolution.
- Early scientists like **Buffon and Lamarck** used comparative anatomy to determine relationship
- between species. They believed that organisms with similar structures have originated

- Genetic drift is concerned with **changes in gene frequencies in small populations by chance**.
- The gene frequencies will continue to fluctuate until a new mutation is either lost or is fixed.
- When a species moves from its original home into a new area, the individuals are not fully suited to the new environment.
- They are thus exposed to mutations with their gene pool markedly different from the parent population.
- Moreover, when a species is expanding continuously, the populations invade new areas and become more different genetically after establishing themselves in those areas.
- This finally results in the modification of these populations into new species. Therefore, genetic drift determines evolution.

## 5. REPRODUCTIVE ISOLATION

- Reproductive isolation is regarded as one of the most important factors of evolution.
- It does not **permit the interbreeding** among the individuals of different species.
- It helps in **splitting of the species** and in the establishment of new species, which is responsible for bringing about evolution.

## EVIDENCES OF EVOLUTION

- Evolution leaves **observable signs**.
- Darwin's theory of evolution was mainly based on the evidence from the geographical distribution of species and from the fossil record.
- However, there have been many evidence as biology progressed.

### EVIDENCE FROM BIOGEOGRAPHY

- It was the **geographical distribution of species** (plants and animals) – biogeography– that first suggested the idea of evolution to Darwin.
- Islands have many species of plants and animals that are endemic but closely related to species of the nearest mainland or neighbouring island.
- Consider **armadillos**, the armoured mammals that live only in America.
- The evolutionary view of biogeography predicts that contemporary armadillos are modified descendants of earlier species (**glyptodonts**) that occupied these continents, and the fossil record confirms that such ancestors existed.

**FTB**

- Biogeography gives evidence of prehistoric climates, habitats and animal distribution pattern.
- Biogeographic studies show that life forms in different parts of the world have distinctive evolutionary histories.

### SPECIFIC PATTERN OF DISTRIBUTION

Today, comparative anatomy can serve as the first line of reasoning in determining the relatedness of species.

**BTB**

**COMPARATIVE ANATOMY**

- Some snakes have hipbones, which show they once had four legs like lizards, their close cousins.
- Inside some whales and dolphins are small limb bones which show that once had back legs and that their ancestors walked on land.
- These occasionally reappear as tiny rear flippers.

**BIOGEOGRAPHY**

- Modern kangaroos appeared only in Australia which evolved from extinct giant kangaroos.
- Darwin found **13** species of finches in Galapagos, not found anywhere else in the world, as far as he knew.
- He concluded that the finches had evolved from a common ancestral group that probably reached the Island many generations earlier.

- Darwin noticed that South America locked rabbits, even though the environment was quite suitable to them.
- He concluded that there are no rabbits in South America because rabbits originated somewhere else, and they had no means to reach South America.

## FACTORS INHIBITING DISTRIBUTION OF ORGANISMS

- Bio-geographical studies show that species have restricted distribution from the centre of origin due to some kind of barrier like **physical** such as an ocean, desert or mountain, **environmental** such as an unfavourable climate, or **ecological** such as the presence of organism that compete with it for food as shelter.

## EVIDENCES FROM PALEONTOLOGY

- The succession of fossil forms is strong evidence in Favor of evolution.
- It provides a visual record in a complete series showing the evolution of an organism.
- **Oldest known fossils:** For instance, evidence from biochemistry, molecular biology, and cell biology places prokaryotes as the ancestors of all life and predicts that bacteria (prokaryotes) should precede all eukaryotic life in the fossil record.
- Indeed, the **oldest known fossils are prokaryotes**.
- **Chronological sequence of vertebrate fossil:** Another example is the chronological appearance of the different classes of vertebrate animals in the fossil record.
- Fossil fishes, the earliest vertebrates, with amphibians next, followed by reptiles, then mammals and birds.
- This sequence is consistent with the history of vertebrate descent and with complexity of their organ system.
- The **evolution of horse** provides an example of such a history.

**FTB**

- **Paleontology** is the science of discovery, identification and interpretation of fossils.
- Sometimes the fossil record allows us to trace the history of one particular organism, such as the modern-day horse **Equus**.
- The earliest horses had **four toes**. Over time the number of toes **reduced to three**, in the modern horses to one, a large central toe that ends in a hoof.
- The evidence of fossil records supports the **common descent hypothesis** (descent of modern organism from common ancestors).

**PTB**

- **Fossils** are either the actual remains or - traces of organisms that lived in ancient geological times.
- The organism may be embedded in sand, resin or ice, or an impression or cast is made of the body parts, the tissue being replaced or petrified

- In the isolation of the Galapagos Island, the original finches had probably evolved into **13 species**.

**PALAEONTOLOGY**

Evolution of Horse occurred in the following way.

1. Eohippus (50 million years ago)
2. Mesohippus (35 million years ago)
3. Meryhippus (10 million years ago)
4. Pliohippus (5 million years ago)
5. Equus (At Present)

**KPK**

- Evolution is a conservative process and tends to remodel the existing ones.
- Some of the **examples of vestigial organs** in human beings are nictitating membranes of eye, appendix, coccyx or tail bone and mammary glands of male.
- Vestigial organs are not confined to man only.
- Whale has vestiges of hind limbs buried in the flesh, where its tail begins.
- Python (snakes) has tiny bony structures beneath the skin, which are the remains of its

by silica or calcium carbonate minerals.

- Most fossils are found in **sedimentary rocks**.

## EVIDENCES FROM COMPARITIVE ANATOMY

- Anatomical similarities between species grouped in the same taxonomic category bring another support to the theory of the Descent with modification.
- **For example,** the same skeletal elements make up the forelimbs of humans, cats, whales, bats, and all other mammals, although these appendages have very different functions.
- The basic similarity of these forelimbs is the consequence of mammals from a common ancestor.
- The arms, wings, flippers, and forelegs of different mammals are variations on a common anatomical theme that has been modified for divergent functions.
- Similarity in characteristics resulting from common ancestry is known as homology, and such anatomical signs of evolution are called homologous structures.
- Comparative anatomy supports that evolution is a **remodelling process** in which ancestral structures that functioned in one capacity become modified as they take on new functions.
- The flower parts of a flowering plant are homologous.
- They are considered to have evolved from leaves, to form sepals, petals, stamens and carpels.

## VESTIGIAL ORGANS

- They are those organs that have lost all or most of their functions through evolution.
- Their presence is a **convincing evidence of evolution**.
- The oldest homologous structures are vestigial organs, rudimentary structures of marginal, if any, use to the organism.
- Vestigial organs are historical remnants of structures that had important functions in ancestors but are no longer essential presently.
- For instance, the skeletons of whales and some snakes retain vestiges of the pelvis and leg bones of walking ancestors, vermiform appendix in carnivores, ear muscles in man etc.

## POINT TO PONDER

- There are about **90 vestigial structures** present in our body
- Vermiform appendix is vestige of the caecum.
- Coccyx or tailbone is the remnant of a lost tail.
- The wisdom teeth are vestigial third molar that human ancestors used to help in grinding down plant tissue.
- Humans have ear muscles that are minimally developed and non-functional, but some people are able to move their ears in various directions.

FTB

ancestral hind limb.

- Baleen whales and bon constrictors have no functional legs but still develop the vestigial pelvic bones and even miniature leg bones buried in their sleek sides.

**BTB**

- The most recent estimate of the age of the earth was published in the journal nature in **August 2005**.
- The age of the earth as estimated from the age of meteorite is **4569 million years** old.

**KPK**

**DIVERGENT EVOLUTION**

- **Adaptive radiation** is one example of divergent evolution.
- Divergent evolution is the process of two or more related species becoming more and more dissimilar.
- If species have diverged while adapting to different environmental conditions, they should do so only in certain features, retaining ancestral traits unmodified by this adaptive process.

## HOMOLOGOUS ORGANS REPRESENT DIVERGENT EVOLUTION

- Body parts that are **similar in structure** but **different in function** because they were inherited from a common ancestor are called homologous structures and their similarity is called homology.
- This pattern of evolution in which different species have been evolved from **common ancestors at different habitats** is known as divergent evolution.
- For example, the basic structure of all the flowers is same, Similarly the limb-bone pattern of all tetrapods from amphibian to mammals has the same structural plan, it is called pentadactyl limb.
- **Vertebrate forelimbs** are used for **flights** (birds and bats), orientation during **swimming** (front flipper of whales and dolphins) running (horses + cats' paws), **climbing** (arboreal izard), or **swinging** from tree branches.
- Yet, all vertebrate forelimbs contain the same sets of bones, muscles, nerves and blood vessels organized in similar ways and with similar mode of development, despite their dissimilar functions.

## ANALOGOUS ORGANS REPRESENT CONVERGENT EVOLUTION

- On the other hand, the organs which are **similar in function but differ in structure** are called analogous organs, e.g., wings of the bird, bats and insects.
- Analogous structures are of evolutionary interest because they demonstrate the **population with separate ancestries may adapt in similar ways to similar environmental demands**.
- This pattern of evolution in which different species have been evolved from **different ancestors at common habitat** is known as convergent evolution.

PTB

## COMPARITIVE EMBRYOLOGY

- Closely related organisms go through similar stages in their embryonic development.
- For example, all vertebrate embryos go through a stage in which they have gill pouches on the sides of their throats.
- At embryonic stage of development, similarities between fishes, frogs, snakes, birds, humans, and all other vertebrates are much more apparent than differences.
- As development progresses, the various vertebrates diverge more and more, taking on the distinctive characteristics of their classes.
- In fish, for example, the gill pouches develop into gills; in terrestrial vertebrates, these-embryonic structures become modified for other functions, such as the eustachian tubes that connect the middle ear with the throat in humans.
- Comparative embryology can often establish **homology among**

- The result should be that species resemble each other in many traits, leaving clues to their history of ancestry in the fine structure of their adaptations.
- The term homology means "**similarity due to shared developmental pathways.**"
- Homology can thus be recognized when structures evolve from the same precursor cells in embryos.
- Darwin argued that the most logical explanation for this sharing of pathways among different organisms was **(1)** that organisms had diverged from common ancestors, and **(2)** that early developmental stages had changed relatively less than later stages during evolution.
- The **red fox and the kit fox** provide an example of two species that have undergone divergent evolution.
- The **red fox** lives in mixed farmlands and forests, where its red color helps it blend in with surrounding trees.
- The **kit fox** lives on the plains and in the deserts, where its sandy colour helps

structures, such as gill pouches, that become so altered in later development that their common origin would not be apparent by comparing their fully developed forms.

## EVIDENCE FROM MOLECULAR BIOLOGY

- Almost all living organisms use the same basic biochemical molecules, including DNA, ATP and Almost all enzymes.
- Further, organisms utilize the same DNA triplet code and the same and identical acids in their proteins.
- Organisms even share the same type of introns.
- Evolutionary relationships among species are reflected in their DNA and proteins—in their genes and gene products.
- If two species have genes and proteins with sequences of monomers that match closely, the sequences must have been copied from a common ancestor.
- For example, a common genetic code brings evidence that all life is related.
- Molecular biology has thus provided **strong evidence in support of evolution** as the basis for the unity and diversity of life.
- Similarly, taxonomically remote organisms, such as humans and bacteria, have some proteins in common.
- For instance, cytochrome c, a respiratory protein used in ETC is found in all aerobic species.
- There is obviously no functional reason why these elements need to be similar, but their similarity can be explained by descent from a common ancestor.

KPK

## EVIDENCE FROM BIOCHEMISTRY

- Living organisms exhibit similarity in biochemistry.
- The protoplasm of all living beings has roughly the same composition and properties
- The DNA and RNA show remarkable similarity in structure and function.
- The process of protein synthesis is essentially identical in all living beings.
- The occurrence of ATP as the reservoir of energy emphasizes the aspect of common origin.
- Cytochrome c also plays role in programmed cell death.

## EVIDENCE FROM EMBRYOLOGY

- The embryologist **Karl Von Baer** was the first to consider the fact that, no matter how great adult vertebrates may differ from each other in structure and habit, their embryos resemble one another and provides evidence of evolution.
- For example, all multicellular animals begin their life as unicellular fertilized egg or zygote, which by the cell division forms hollow blastula, followed by gastrula.

conceal it from prey and predators.

- The **ears** of the kit fox are larger than those of the red fox.
- The kit fox's large ears are an adaptation to its desert environment.
- The enlarged surface area of its ears helps the fox get rid of excess body heat.
- Similarities in structure indicate that the red fox and the kit fox had a common ancestor.
- As they adapted to different environments, the appearance of the two species diverged.

### CONVERGENT EVOLUTION

- The **convergent evolution** is the process whereby organisms not closely related (not monophyletic), independently evolve similar traits as a result of having to adapt to similar environments or ecological niches.
- In convergent evolution, **unrelated species become more and more similar in appearance** as they adapt to the same kind of environment.
- The **Cactus**, which

- The cleavage, blastula and gastrula are almost fundamentally similar in all metazoan groups including man.
- In the development of frog, there is fish like stage of tadpole
- **Haeckle** was impressed by the striking similarity that exists between the embryonic development of higher organisms and evolutionary history of the race.
- This led to the belief that organism during its development repeat its ancestral history.
- **Recapitulation theory of Von Baer or Biogenetic law of Hackle state that ontogeny (embryonic development of individual) recapitulates phylogeny (evolutionary history of The race) or "in development each individual tends to climb to its own family tree".**

grows in the American desert resemble to the Euphorbia, which grows in the African deserts.

- Both have fleshy stems armed with spines.
- These adaptations help the plants store water and ward off predators.
- Some aspects of the lens of eyes also evolved independently in various animals.

# NEW TOPICS ACCORDING TO AN NMDCAT SYLLABUS 2025

## Effects of Smoking on Respiratory System

### FTB

- Cigarette smoking causes about **87%** of lung cancer.
- Besides lung cancer, cigarette smoking is also a major cause of cancer of the mouth, larynx and oesophagus.
- Cigarette smoking causes other lung diseases e.g., chronic bronchitis, emphysema.
- Cigarette smokes contain chemicals which irritate the air passages and lungs, causing early morning cough.
- Smokers are likely to get pneumonia because damaged or destroyed cilia cannot protect lungs from bacteria and viruses that float in the air.
- Almost immediately, smoking can make it hard to breathe. Within a short time, it can also worsen asthma and allergies.

### PTB

- Smoking especially in young adults is the most potential threat of lung cancer.
- The chances of lung cancer are ten times more in those persons who smoke or live in smoky and congested areas as compared to those who do not smoke.
- It is now estimated that **90%** of lung cancer is caused by smoking. Recent research indicates that more than ten compounds of tar of tobacco smoke are involved in causing cancer.

### BTB

- There are many effects of smoking on our respiratory system such as 87% of cigarette smokers also develop lung cancer.
- The smoking causes cancer of mouth, larynx and oesophagus.
- Smoking also causes many other diseases such as chronic bronchitis and emphysema.
- The smoke of cigarette contains chemicals which irritate the respiratory tract and lung which results in early morning coughing and wheezing.
- It is indirect cause of pneumonia because cigarette smoke damages or destroys cilia.
  Thus microbes cannot be trapped and are easily settled in respiratory system.
- Tobacco smoke may cause swelling in air passage that produce the mucus which can block air ways.
  This cause lung infection and may damage the alveoli.

### KPK

- Irritation of the trachea (windpipe) and larynx (voice box)
- Reduced lung function and breathlessness due to swelling and narrowing of the lung airways and excess mucus in the lung passages
- Impairment of the lungs' clearance system, leading to the build-up of poisonous substances, which results in lung irritation and damage
- Increased risk of lung infection and symptoms such as coughing and wheezing
- Permanent damage to the air sacs of the lungs.

### STB

- The effect of tobacco smoking on respiratory system is the larynx and tracheal passage irritations.

# NEW TOPICS ACCORDING TO NMDCAT SYLLABUS 2025

## Functions of Hormones naturally produced by plants

FTB

### GROWTH RESPONSES IN PLANTS

- Plants generally adjust themselves to changing environment by growth.
- The changes in plant shape or functions are often regulated by plant hormones (growth substances) produced in response to environmental factors.
- The plant hormones act at the level of cells to induce cell division, enlargement or cell maturation.

### PLANT GROWTH REGULATORS

- Plants are co-ordinated by chemicals commonly known as plant hormones, which necessarily move from their sites of synthesis to the sites of action, and because their effects are usually on some aspect of growth, they are called growth regulators.
- Five major types of growth regulators are recognized: (a) auxins (b) gibberellins (c) cytokinins (d) abscisic acid (e) ethene
- Auxins, gibberellins and cytokinins are called growth promoters because of their general role in promotion of growth .
- Abscisic acid and ethene are called growth inhibitors.

### AUXINS

- An auxin or indole-3-acetic acid (IAA), was the first plant hormone identified. It is manufactured primarily in the shoot tips (in leaf primordia and young leaves), in embryos, and in parts of developing flowers and seeds.
- They are mainly responsible for cell elongation.

### GIBBERELLINS

- The gibberellins are widespread throughout the plant kingdom, and more than 75 have been isolated, to date.
- Rather than giving each a specific name, the compounds are numbered, for example, GA1, GA2, and so on.
- Gibberellic acid 3 (GA3) is the most widespread and the most thoroughly studied.
- The gibberellins are especially abundant in seeds and young shoots where they control stem elongation by stimulating both cell division and elongation.

### CYTOKININS

KPK

- Plants show growth responses by releasing certain chemicals or by showing differential growth rate or movement. Plant Growth Substances or Hormones of plants are referred as Phyto Hormones.
- Phyto Hormones are organic substances which are naturally produced in plants; control the growth or other physiological functions, at a sight remote from its place of production and active in extreme minute quantities.

#### 1. AUXINS

- Auxin is a Greek word, which means "to increase".
- Naturally occurring auxin is a hormone that is produced in the apical meristems of shoots and the tips of coleoptiles.
- Indole acetic acid with other related compounds are collectively called as auxin.

- These are named because of their role in cell division (cytokinesis), the cytokinins have a molecular structure similar to adenine.
- Naturally occurring zeatin, isolated first from corn (Zea mays), is the most active of the cytokinins.
- Cytokinins are found in sites of active cell division in plants, for example, in root tips, seeds, fruits, and leaves.

## ABSCISIC ACID

- Its principal effect is inhibition of cell growth.
- ABA increases in developing seeds and promotes dormancy.
- If leaves experience water stress, ABA amounts increase immediately, causing the stomata to close.

## ETHYLENE OR ETHENE

- Ethylene or ethene is a simple gaseous hydrocarbon produced from an amino acid and appears in most plant tissues in large amounts when they are stressed.
- It diffuses from its site of origin into the air and affects surrounding plants as well.
- Ethylene stimulates the ripening of fruit and initiates abscission of fruits and leaves.

| Part Affected | Auxins | Gibberaline | Cytokinins | Abscisic Acid | Ethene |
|---|---|---|---|---|---|
| Stem | Promote cell enlargement behind apex. Promote cell division in cambium | Promote cell enlargement in the presence of auxin. Promote leave growth. | Promote cell division in apical meristem and cambium. Promote leave growth | Inhibit growth during stress, e.g, drought, salinity and water logging. | Inhibit growth during stress, e.g, drought, salinity and water logging. |
| Root | In low conc. promote growth. In high conc. inhibit growth. Promote growth from cuttings and calluses. | Nil | Inhibit primary root growth. Promote lateral root growth. | Nil | Inhibit root growth |
| Floral buds | Promote but initiation | Promote bud initiation | Promote bud initiation Promote lateral bud growth Break bud dormancy | Promote bud initiation | Promote bud initiation |
| Flowering | Nil | Promote in long day plants Inhibit in short day plants Acts as substitute for red light Antagonistic to Abscisic acid | Nil | Promote in short day plants Inhibit in long day plants Act as substitute for red light Antagonistic to gibberellins | Promote in pineapple |
| Apical dominance | Promote | Enhance the action of auxin | Inhibit | Nil | Nil |
| Fruit growth | Promote ripening | Promote ripening | Promote ripening | Nil | Promote ripening |

- Auxins control and regulate many physiological processes.
- Auxin travels by diffusion toward the base of the plant, where it controls the lengthening of the shoot and the coleoptile, chiefly by promoting cell elongation.
- Auxin also plays a role in differentiation of vascular tissue and initiates cell division in the vascular cambium.
- It often inhibits growth in lateral buds, thus maintaining apical dominance.
- The same quantity of auxin that promotes growth in the stem inhibits growth in the main root system.

### 2. GIBBERELLINS

- The gibberellins were first isolated from a parasitic fungus that causes abnormal growth in rice seedlings.
- They were subsequently found to be natural growth hormones present in many plants.
- The most dramatic effects of gibberellins are seen in dwarf plants, in which

| | | | | | |
|---|---|---|---|---|---|
| Parthenocarpy | Rarely promote | Promote | Rarely promote | Nil | Nil |
| Leaf senescence | Delay | y | Delay | Promote | Nil |
| Seed dormancy | Nil | BreakDela | Break | Promote | Nil |
| Abscission | Inhibit | Inhibit | Inhibit | Promote | Nil |
| Stomatal opening | Nil | Nil | Promote | Inhibit | Nil |

**SCIENCE TIDBITS**

Different cytokinins: auxin ratios change the nature of organogenesis. If kinetin (cytokinin) is high and auxin low, shoots are formed; if kinetin is low and auxin high, roots are formed. Lateral bud development, which is retarded by auxin, is promoted by cytokinins.

**PTB**

## (A) AUXINS:

- These are indole acetic acid (IAA) or its variants.
- In stem, promote cell enlargement in region behind apex. Promote cell division in cambium.
- In root, promote growth at very low concentrations. Inhibit growth at higher concentrations, e.g., geotropism. Promote growth of roots from cuttings and calluses.
- Promote bud initiation in shoots but sometimes antagonistic to cytokinins and is inhibitory.
- Promote apical dominance and fruit growth. They can sometimes induce parthenocarpy.



## COMMERCIAL APPLICATIONS:



- Discovery of IAA led to the synthesis of a wide range of compounds by chemists.
- The synthetic auxins are economical than IAA to produce and often more active because plants generally do not have necessary enzymes to break them down.

| SYNTHETIC AUXINS | |
|---|---|
| NAA (Naphthalene acetic acid)<br>Indole propionic acid | Stimulates fruiting - help natural fruit set. Sometimes causes fruit setting in absence of pollination (parthenocarpy) |
| 2,4 D (2,4 Dichloro phenoxy acetic acid) | Selective veed killer; Kills broad leaved species (dicots). Used in cereal crops and lawns to eliminate weeds.<br>Inhibits sprouting of potatoes.<br>Prevents premature fruit drop (retards abscission) |



the application of gibberellins restores normal growth, and in plants with a rosette form of growth, in which gibberellins cause bolting.

- Gibberellins cause seed germination in grasses.
- In the barley seed, the embryo releases gibberellins that cause the aleurone layer of the endosperm to produce several enzymes, including alpha-amylase, which breaks down the starch stored in the endosperm, releasing sugar.
- The sugar nourishes the embryo and promotes the germination of the seed.

### 3. CYTOKININS

- The cytokinins were first discovered as a consequence of their capacity to promote cell division and bud formation in cultures of plant tissues.
- They are chemically related to certain components of nucleic acids.
- Cytokinins can also act along with

## (B) GIBBERELLINS:

- These are produced commercially from fungal cultures.
- Promote cell enlargement in the presence of auxins. Also promote cell division in apical meristem and cambium.
- Promote 'bolting' of some rosette plants.
- Promote bud initiation in shoots of chrysanthemum callus.
- Promote leaf growth and fruit growth. May induce parthenocarpy.
- In apical dominance, enhance action of auxins.
- Break bud and seed dormancy.
- Sometimes may substitute for red light. Therefore, promote flowering in long-day plants, while inhibit in short-day plants.
- Cause delay in leaf senescence in a few species.

## COMMERCIAL APPLICATIONS:

- Some of their commercial applications are as under:
  1. GA promotes fruit setting e.g. in tangerines and pears and are used for growing seedless grapes (parthenocarpy) and also increase the berry size.
  2. GAs is used in the brewing industry to stimulate α-amylase production in barley and this promotes malting.
  3. To delay ripening and improve storage life of bananas and grape fruits.

## (C) CYTOKININS:

- Promote stem growth by cell division in apical meristem and cambium.
- Inhibit primary root growth.
- Promote lateral root growth.
- Promote bud initiation and leaf growth.
- Promote fruit growth but can rarely induce parthenocarpy.
- Promote lateral bud growth, also break bud dormancy.
- Cause delay in leaf senescence.
- Promote stomatal opening.

## COMMERCIAL APPLICATION:

- Cytokinins delay aging of fresh leaf crops, such as cabbage and lettuce (delay of senescence) as well as keeping flowers fresh.
- They can also be used to break dormancy of some seeds.

## (D) ABSCISIC ACID:

- Inhibits stem and root growth notably during physiological stress, e.g. drought, and waterlogging.
- Promotes bud and seed dormancy.
- Promotes flowering in short day plants, and inhibits in long day plants (antagonistic to gibberellins).
- Sometimes promotes leaf senescence.
- Promotes abscission.
- Promotes closing of stomata under conditions of water stress (wilting).

auxin to cause cell division in plant tissue culture.

- In tobacco pith cultures, a high concentration of auxin promotes root formation, while a high concentration of cytokinins promotes bud formation.
- In intact plants, cytokinins promote the growth of lateral buds, acting in opposition to the effects of auxin.
- Cytokinins prevent senescence in leaves by stimulating protein synthesis.

### 4. ABSCISIC ACID (ABA)

- After the discovery of auxins, plant physiologists suspected a dormancy-causing chemical in plants.
- At last, a substance that promotes abscission of cotton fruit was purified and was called "abscission II".
- At the same time, a substance was obtained from Bitula pubescence, which promoted bud dormancy and was called 'dormin', similar to abscission II on chemical analysis.

## COMMERCIAL APPLICATION:

- Abscisic acid can be sprayed on tree crops to regulate fruit drop at the end of the season.
- This removes the need for picking over a large time-span.

## (E) ETHENE:

- Inhibits stem growth, notably during physiological stress.
- Inhibits root growth.
- Breaks dormancy of bud.
- Promotes flowering in pineapple.
- Promotes fruit ripening.

## COMMERCIAL APPLICATION:

- Ethene induces flowering in pineapple.
- Stimulates ripening of tomatoes and citrus fruit.
- The commercial compound ethephon breaks down to release ethene in plants and is applied to rubber plant to stimulate the flow of latex.

**STB**

- Phytohormones are synthesized by plants in minute concentration and exert their effect either by altering gene expression, activating or inhibiting enzymes or changing properties of the membrane.
- They are produced in young embryonic tissues as there is no specific organ for their production in plants.
- There are five kind of plant hormones.
- These are: i. Auxins ii. Gibberellins iii. Cytokinins iv. Abscisic acid v. Ethene

## I. AUXINS (GR. AUXANO = TO INCREASE):

- Auxins is a class of plant growth substances both natural and synthetic first revealed by Fritz-Went (1926).
- They were the first of the major plant hormones to be discovered and a major coordinating signal in plant development.
- Indole-acetic acid (IAA) is the principal type of auxin of higher plants, synthesized at the apices of stem and root (apical meristem).
- In addition to (IAA), other naturally occurring auxins are:
  - 4-chloro-indole acetic acid
  - Phenyl acetic acid (PAA)
  - Indole-3 butyric acid (IBA)
- The synthetic auxins include:
  - Naphthalene acetic acid (NAA)
  - 2,4-dichloro-phenoxy acetic acid (2, 4-D)
- Auxins co-ordinate development at all levels in plants, from the cellular level to organs and ultimately the whole plant.

## ROLE OF AUXINS:

- The abscission II was later named "abscisic acid" due to its abscission character and acidic nature
- Abscisic acid causes bud dormancy and seed dormancy.
- It inhibits active growth of seedling flowering in long day plants and promotes abscission.
- During stress conditions (water deficiency or drought) the concentration of abscisic acid increases which causes stomata to close and facilitates influx of water into the roots.
- Therefore abscisic acid is also called stress hormone that helps plant cope with adverse conditions.

**5. ETHYLENE**

- Ethylene, a gaseous hormone diffuses through the plant in air spaces.
- It inhibits root growth and development of axillary buds when present in high concentration.
- Ethylene also induces fruit ripening and

- **a) Cell division and cell-enlargement:**
  Stimulates cell division, cell enlargement, and increases length of plant.
  Stimulates wall loosening factor (e.g., elastin) to loosen the cell wall. Effect is stronger with gibberellins.
  Also stimulates cell division if cytokinins are present.
  Xylem tissues can be generated when auxin concentration equals cytokinin levels.
- **b) Initiation of roots:**
  Initiates development of adventitious roots when applied at cut base of stem.
- **c) Abscission:**
  In mature leaves and fruits, when auxin production diminishes, a layer of thin-walled cells forms at the base of petiole and fruit stalk (abscission layer), causing fall of leaves and fruits with slight jerk.
- **d) Growth of fruit:**
  Auxin stimulates cell division.
  Tissues of ovary divide and enlarge under auxin to support fruit setting.
- **e) Parthenocarpy:**
  Auxin use can produce parthenocarpic (seedless) fruits.
- **f) Apical dominance:**
  Auxin inhibits growth of lateral buds beneath the apical bud.This is known as apical dominance.
  Removal of apical bud promotes growth of lateral buds.
- **g) Weedicides:**
  Auxins are selective weed killers.
  2,4-dichlorophenoxy acetic acid (2,4-D) is used to kill weeds in lawns and cereal crops.
- **h) Flowering:**
  Auxin plays a minor role in the initiation of flowering.
  In low concentrations, it can delay the senescence of flowers.



## II. GIBBERELLINS:



- A group of chemicals that promote cell division and cell elongation.
- First noticed in Gibberella fujikuroi fungus, which infected rice seedlings and caused a disease called bakanae (foolish seedling).
- Infected seedlings grew excessively tall and fell over without producing grains.
- Extracts from the fungus also induced the same disease when applied to rice seedlings, indicating a chemical cause.

## DISCOVERY:

- T. Yabuta and T. Hayashi isolated the active substance and named it Gibberellin.
- Over 70 gibberellins have been identified, found in roots, stems, and leaves of higher plants.

## ROLE OF GIBBERELLIN:

- Stimulates cell division and elongation (even more than auxin).

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Increases senescence in plant cells and organs.

- The promotion of leaf abscission involves decrease auxin and increase ethylene production.

**BTB**

**AUXINS:**

- These are a class of plant hormones which are mainly responsible for bringing about cell elongation in shoots.
- They are also known as to control many physiological processes and influence other hormones.
- The principal natural auxins are chemically indole acetic acid (IAA).
- Its formula is $C_{10}H_9NO_2$.
- Besides the natural auxins, a number of synthetic auxins have been developed. These include:
  - 2-4 dichlorophenoxy acetic acid
  - alpha naphthalene acetic acid etc.
- Auxins are synthesized in the tips of shoots and roots.

- Prevents genetic and physiological dwarfism.
- Mobilizes stored food in endosperm by producing amylase (enzyme that converts starch into sugar for embryo).
- Stimulates flowering, fruit development, bud sprouting, growth of pollen tube, and parthenocarpy.

## III. CYTOKININS:

- A group of substances (natural and synthetic) that react with auxin to induce cell division.
- Originally extracted from coconut milk, herring sperm DNA, and yeast extract.
- Zeatin is a natural cytokinin from immature corn grains.
- Kinetin is a synthetic cytokinin with similar effects

## ROLE OF CYTOKININS:

- Initiate rapid cell division but only in presence of auxin.
- Delay senescence (aging) of detached leaves.
- Prevent yellowing by maintaining chlorophyll.
- Break seed dormancy and promote fruit development in some species.

## IV. ABSCISIC ACID (ABA):

- Unlike growth-promoting hormones like auxins, gibberellins, and cytokinins, abscisic acid (ABA) is a growth inhibitor.
- It is produced by plants during adverse environmental conditions, such as drought or the onset of winter.

## FUNCTIONS OF ABA:

- Induces dormancy in buds and seeds.
- Causes stomata to close.
- Turns leaf primordia into scale to protect buds.
- Promotes senescence.

## V. ETHENE (ETHYLENE):

- Ethene is a gas with the most important role in triggering fruit ripening.
- Increases permeability of cell membranes, allowing enzymes to destroy chloroplasts.
- This unmasks red and yellow pigments, giving the fruit its ripened color.

## ALSO RESPONSIBLE FOR:

- Leaf abscission.
- Breaking dormancy of buds and seeds in some species.
- Initiating flowering in some plants (e.g., pineapple).

BTB

## ABSCISIC ACID (ABA):

### GIBBERELLINS:

- These are growth regulating substances bring about a rapid and great elongation of the stem and various other developmental processes like germination, dormancy, flowering, leaf and fruit senescence (ageing).
- There are more than 75 different types of gibberellins have been discovered. They are named as $GA_1$, $GA_2$, $GA_3$ and so on.
- The most active and best known gibberellin is $GA_3$ (Gibberellic acid, $C_{19}H_{22}O_6$) obtained from rice fungus.

### CYTOKININS:

- These are a class of plant growth hormones that promote cytokinesis so called cytokinins.
- Chemically these are derivatives of adenine like kinetin and zeatin. ($C_{10}H_{13}N_5O$). These are synthesized in the tissues of plants where cell division occurs.

- It is the plant hormone which helps in many plant developmental processes, including bud dormancy, fruit drop, leaves drop and also involve in stress responses.
- ABA is chemically a terpenoid and is formed in leaves, fruits and seeds.
- Like the other growth substances ABA moves in the vascular system.
- Its formula is $C_{15}H_{20}O_4$.
- The abscisic acid owes its name to its role in abscission of plant leaves.

## ETHYLENE:

- It is relatively simple organic molecule that exists as a gas at normal temperature.
- It is produced naturally in trace amount in most of the organs of higher plants.
- The main role of it is to promote fruit ripening.
- However, it also involves in breaking bud dormancy, promote abscission of fruit and leaves etc.
- Its formula is $C_2H_4$.

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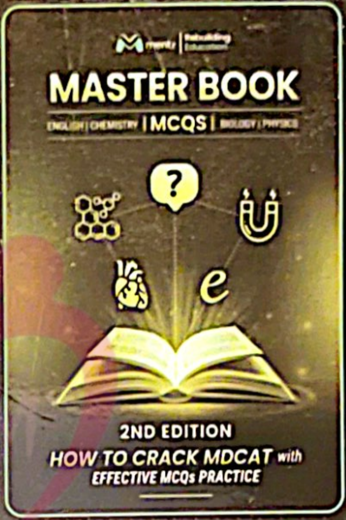


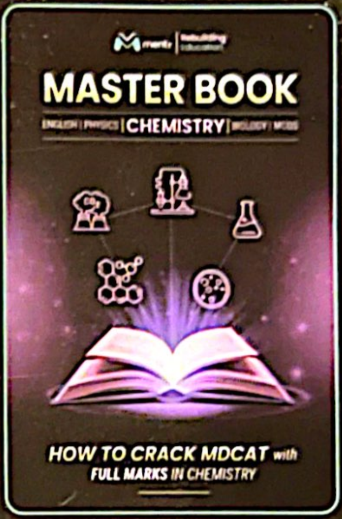


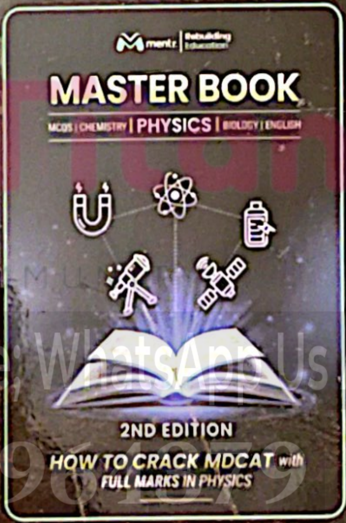


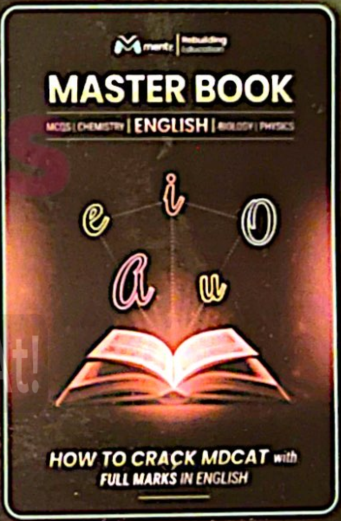




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